Using the *Fire Frequency Tool* to Calculate Fire Frequency from Disparate Temporal – Spatial Data Sources

Fire frequency is defined as the fire occurrence or rate, such as the average time interval between successive fires, or the number of fires within a specific period of time (McPherson and others 1990; Agee 1993). The FRCC Guidebook specifically defines fire frequency and the associated term mean fire return interval as the average number of years between fires for representative stands (Barrett and others 2010). Fire frequency is an important ecological and resilience measure because fire is a keystone process in most ecosystems, even rare interval systems (Keane and others 2002). Fire frequency is also an important fuel management measure as it is one of the only measures that provide an indication of fine fuel consumption.

The Fire Frequency Tool (FFT) is included with the Fire Regime Condition Class Mapping Tool ($FRCC_{MT}$) enables users to create spatial fire frequency inputs to the $FRCC_{MT}$ at a similar scale as SClass and fire severity, using multiple data sources as input depending on which dataset best captures the fire history within different historic sub-periods. Fire frequency data typically considered for input to the FFT typically include LANDFIRE disturbance maps, Monitoring Trends in Burn Severity (MTBS) maps, as well as local fire history maps.

FIRE HISTORY DATA SOURCES

Spatial fire history data can come from a variety of sources depending on what historical data is available. Fire history from the later part of the 20th century and the 21st century can be obtained from sources that utilize remotely sensed data. Since 1984, the Monitoring Trends in Burn Severity (MTBS) program has spatially documented large wildland fires. Since 1999, the LANDFIRE project has produced disturbance layers that include both wildland fire and prescribed fires. In order to obtain spatial fire history data prior to the start of the MTBS records in 1984, it is necessary to rely on digitized fire history atlases which are maintained by some land management units. These historic atlases will contain the perimeters of fires which have occurred. In order to utilize historic atlases, they have to first be digitized into an electronic format which facilitates their use with a geographic information system (GIS).

Monitoring Trends in Burn Severity

Monitoring Trends in Burn Severity is a project which maps the burn perimeters of fires across all lands of the United States. MTBS datasets developed by the USDA Forest Service Remote Sensing Application Center show data for each large wildland fire in the United States recorded in federal and state fire incident databases. Determination of the perimeter of each of these fires is accomplished by utilizing a differentiated Normalized Burn Ratio between pre-fire and post-fire Landsat satellite scenes containing each of the fires (MTBS 2014).

Perimeters of wildland fires exceeding 1000 acres in the western US and 500 acres in the eastern US are represented as polygon features in a shapefile. The national MTBS shapefile contains attributes of interest including fire year, size in acres, and fire id. Fire Year will be of most interest while calculating fire frequency in that the year the fire burned will allow us to temporally partition the fires based on when they occur, identifying which fires occurred during the period for which we do not have LANDFIRE Disturbance data. The nationwide MTBS shapefile containing all large wildland fires can be downloaded from the MTBS website at www.mtbs.gov.

Local Fire History Atlas

The third data source that is often available is a local fire history atlas. Local land managers will typically have some sort of history of what fires have burned within their jurisdiction. Historic information about early fires has often been obtained by digitizing hand drawn maps. More recently, policy has directed that this information be reported in incident reports which over time have facilitated the inclusion of fire perimeter data, often in an electronic form. These fire perimeters may have been collected by traversing the perimeter of a fire with a GPS, or utilization of remote sensing technology. Typically this historic fire history data is stored in vector format as polygon features in a shapefile. The temporal extent of local data will vary by unit based on what historical data was recorded and has been retained.

Fire atlases are available for many study areas. Depending on the historic data available from the managing unit, the length of the historic period covered by this data may vary. One way to ascertain the length of historic period for which is represented by the local fire atlas is to load the digital atlas into ArcGIS, open the attribute table and examine the range of years for which the atlas has data. This should enable the user to determine the start and end of the historic sub-period represented in the fire atlas.

CALCULATING FIRE FREQUENCY

Once MTBS, LANDFIRE and fire atlas data have been collected for determining fire frequency, those data layers can be coalesced into a single dataset from which fire frequency can be calculated. This process consists of the following steps:

1. Each of the input datasets are converted into Fire Occurrence rasters which do not overlap temporally. Both the MTBS and local fire history datasets are vector based polygons, which can be converted to a Fire Occurrence raster utilizing the FFT's Fire Polygon to Raster tool. The LANDFIRE disturbance layers are raster format, which can be converted to a Fire Occurrence raster with the FFT's Conjoin Disturbance Raster form.
2. The FFT's Fire Rasters to Frequency tool takes the Fire Occurrence rasters from each dataset, conjoining them into a single Fire Occurrence raster, from which a Fire Frequency raster is created using the FRCC definition for fire frequency.

Conversion of Fire Polygons to a Fire Occurrence Raster

To include either an MTBS or fire atlas shapefile containing fire perimeters in the fire frequency calculation, that shapefile must first be converted into a Fire Occurrence raster using FFT's Fire Polygon to Raster tool. The resulting Fire Occurrence raster indicates how many times each pixel has burned.

When converting either the MTBS or fire atlas polygon shapefile to a Fire Occurrence raster, data sets are identified for each given sub-period. Once those date ranges have been identified, only fire perimeters within the sub-period are retained. LANDFIRE Disturbance layers are used for fires from 1999 through 2010 (or later when available). MTBS data was extracted from fire seasons from 1984 through 1998, which was prior to the availability of LANDFIRE data. Local fire atlas data usually contains fire history prior to the MTBS period. In some instances, local fire atlases contain fire history going back more than 100 years, recording fires from the second half of the 19th century.

Conversion of fire perimeter polygons into a Fire Occurrence raster is accomplished from the FFT's Fire Polygon to Raster tool which takes the geometric intersection of the polygons from which a resulting Fire Occurrence raster indicates how many fire polygons were co-located with each intersection polygon, showing the spatial distribution of fire occurrence in the study area during that fire history sub-period. Each pixel will be annotated with how many times that pixel has burned.

To generate a Fire Occurrence raster from either an MTBS or Fire Atlas shape file, click on the Fire Frequency Tool button which is located on the FRCCmt toolbar between the buttons for the Frequency and Severity Editor and the FRCC Mapping Tool as shown in Figure 1. Users running the Fire Frequency tool will need to have the Advanced ArcGIS license in order for the Frequency Tool to have the correct authorizations for the geoprocessing objects it utilizes.

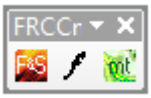

Figure 1: The Fire Frequency Tool button is between the Frequency and Severity Tool and FRCCmt on the FRCCmt Toolbar.

When the Fire Frequency Tool comes up as shown in Figure 2, click on the *Fire Polygon to Raster* button.

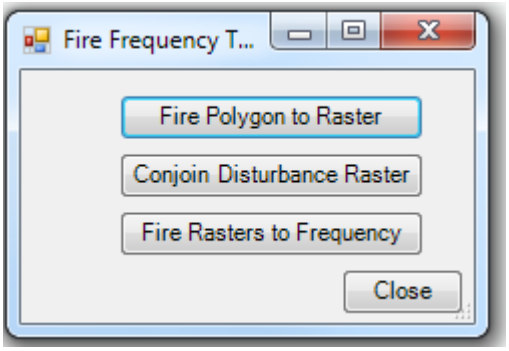

Figure 2: The Fire Frequency Tool.

Prior to running the *Fire Polygon to Raster* tool from the Fire Frequency Tool, the fire history shapefiles for both the Fire Atlas and MTBS will need to have been loaded into ArcGIS and will be visible in the Table of Contents. Likewise, you will need to load into ArcMap a grid which has been clipped to your study area. Either the BpS or Landscape grid (or both) will suffice if they have already been clipped to the study area.

When the *Fire Polygon to Raster* tool appears after hitting the associated button (as shown in Figure 3), set the *Input Fire Polygon* dropdown to the desired (either the MTBS or fire atlas) polygon fire history shapefile. If you are using an MTBS dataset, make sure you are not using a complete shapefile with all fire data for the whole nation. Instead, if you downloaded the MTBS shapefile from the MTBS website (www.mtbs.gov) make sure that you have reduced the nationwide dataset to a subset of fires that are within your region.

Turn on the date filter by selecting *Apply Filter Data*, and setting *Year From* to the start and *Year To* to the end of the fire history sub-period for which this dataset will be used.

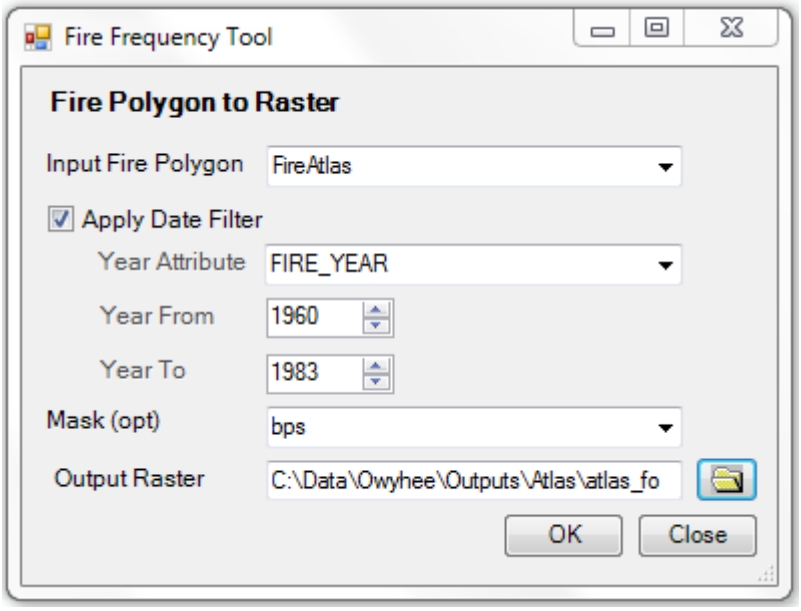

Figure 3: The Fire Polygon to Raster tool setup to generate a Fire Occurrence raster from a Fire Atlas shapefile for the years 1960 - 1983.

In Figure 3, fires will be used from the digitized fire atlas which occurred between the years 1960 and 1983. For this fire atlas, the first fire recorded was in 1960. Starting with fires in 1984, we will use fire perimeters from the MTBS shapefile. When specifying the fire history sub period for creating a Fire Occurrence raster from an MTBS shapefile, it is common to set the *From Year* to 1984 (the year for which MTBS data is first available) and set the *To Year* to 1998, the year preceding the availability of fire history data with the Landfire Disturbance rasters.

A *Mask* raster can optionally be specified. If specified, the resulting Fire Occurrence raster will be clipped to the specified raster. In Figure 3 the BpS raster was specified, which had already been clipped to the HUCs in the Landscape layer.

To set the *Output Raster,* specify the path name where the resulting Fire Occurrence raster will be placed. It is important to note that the folder where the Fire Occurrence raster will be located needs to be empty when the tool starts. An easy way to ensure that the folder is empty is to create the folder when you're navigating to the location where the Fire Occurrence raster will be placed.

It's possible that local fire atlas may contain more recent fire history data than is available from either MTBS or LANDFIRE. As a result, it may be desirable to create one additional Fire Occurrence data from the fire atlas covering more recent fire seasons that are not included in the MTBS or LANDFIRE data.

Conversion of LANDFIRE Disturbance Rasters into a Fire Occurrence Raster

LANDFIRE Disturbance rasters contain a spatial record of disturbance types including both wildland fire and prescribed fire. Each LANDFIRE Disturbance raster contains disturbances from a given year. The FFT's *Conjoin Polygon To Raster* tool extracts fire records from each of the LANDFIRE Disturbance rasters specified and then conjoins them into a single Fire Occurrence raster which represents fire occurrence for the LANDFIRE historic sub-period which extends from 1999 through the most recent year for which LANDFIRE Disturbance rasters exist.

Prior to running the *Conjoin Disturbance Rasters* tool from the Fire Frequency Tool, the LANDFIRE Disturbance rasters will need to have been loaded into ArcGIS and will be visible in the Table of Contents. Likewise, you will need to load into ArcMap a grid which has been clipped to your study area. Either the BpS or Landscape grid (or both) can be loaded into ArcMap.

When the *Conjoin Disturbance Rasters* tool appears (as shown in Figure 4) after hitting the associated Fire Frequency Tool button, select each of the annual disturbance rasters in the *Fire Raster* column in the *Fire Rasters to Conjoin* box. For each of the disturbance rasters selected, in the *Filter Attribute* column, specify the raster attribute that indicates whether the disturbance represents a fire. The tool will only include disturbances where the value in the specified attribute contains the word "fire". When using LANDFIRE Disturbance rasters, the attribute which indicates disturbance type is named "DIST_TYPE.

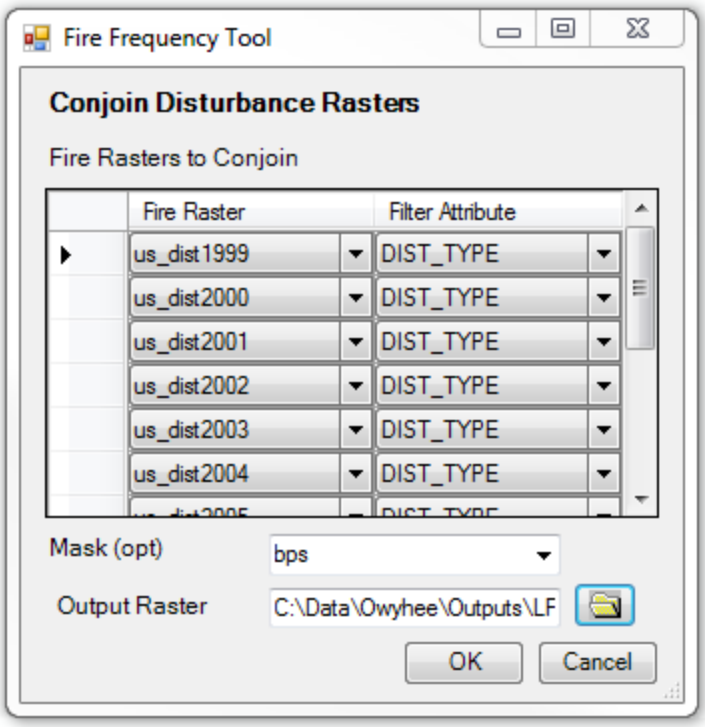

Figure 4: The Conjoin Disturbance Rasters tool setup to generate a Fire Occurrence raster from a set of LANDFIRE Disturbance rasters.

A *Mask* raster can optionally be specified. If specified, the resulting Fire Occurrence raster will be clipped to the specified raster. In Figure 4 the BpS raster was specified, which had already been clipped to the HUCs in the Landscape layer.

To set the *Output Raster,* specify the path name where the resulting Fire Occurrence raster will be placed. It is important to note that the folder where the Fire Occurrence raster will be located needs to be empty when the tool starts. An easy way to ensure that the folder is empty is to create the folder when you're navigating to the location where the Fire Occurrence raster will be placed.

Calculate Frequency from Fire Occurrence

The FFT's *Fire Rasters to Frequency* tool creates a single Fire Occurrence raster from the Fire Occurrence rasters that were derived from the LANDFIRE Disturbance, MTBS and Fire Atlas by conjoining these rasters utilizing a map algebraic add. The resulting Fire Occurrence raster shows fire history for the entire fire history period where each pixel of the raster contains an integer value that indicates how many times that pixel burned. Once the Fire Occurrence raster is created for the complete fire history period, a Fire Frequency raster is derived.

Creation of the Fire Frequency raster from the Fire Occurrence raster involves normalizing the Fire Occurrence raster by landscape and for the Biophysical Setting (BpS). The BpS layer is

downloaded from LANDFIRE and represented a relatively uniform environment for the vegetation and fire regime.

When the *Fire Rasters to Frequency* tool is launched (as in Figure 5), specify each of the Fire Occurrence rasters under *Input Fire Occurrence Rasters*.

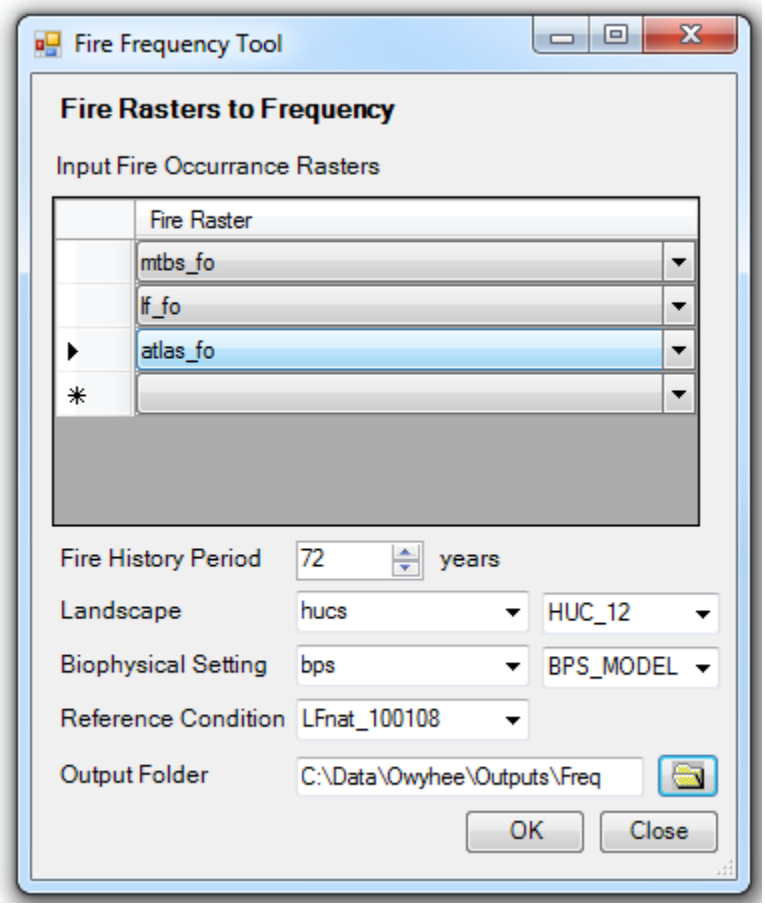

Figure 5: The Fire Rasters to Frequency tool setup to generate frequency output rasters.

Specify the length of the *Fire History Period* which is the number of years between the beginning year of the earliest and the ending year of the most recent Fire Occurrence Rasters specified as inputs. This is the sum of the fire history sub-periods represented by each of the Fire Occurrence rasters specified as inputs for the tool.

Enter the *Landscape* and *Biophysical Setting* rasters and applicable attributes. These rasters will be used in normalizing the frequency calculations across the study area.

Select the *Reference Condition* table that corresponds to the BpS raster used. The reference tables available for selection are found in the Reference Condition database installed with the $FRCC_{MT}$.

To set the *Output Folder,* specify the path name where the output rasters will be placed. It is important to note that the output folder must be empty when the tool starts. An easy way to

ensure that the folder is empty is to create the folder when you're navigating to the location of the output folder.

Intermediate fire frequency metrics are calculated on the combination raster of landscape and BpS which may be of interest to the user. These include:

1. BpS Size (BS) was the pixel count for each BpS within each watershed.

2. Area Burned (AB) was the total number times pixels burned within this BpS/watershed. This calculation took into account that the fire occurrence for a given pixel may have burned more than once.

3. Mean Annual Burned (MAB) was equal to Area Burned divided by the length of the Fire History Period (FHPL).

4. Mean Fire Interval (MFI) is defined as the average number of years between fires. This refers to a grand mean for a BpS within a watershed (Barrett and others 2010). MFI was calculated utilizing BpS Size, Length of the Fire History Period and Mean Area Burned. This relationship was expressed as MFI = BS * FHPL / MAB.

5. Frequency is distinguished from Mean Fire Interval in that MFI only takes into account the spatial fire occurrence data originating from the sources of fire history data mentioned earlier. By contrast, Fire Frequency also considers historical fire regime (Barrett and others 2010). In BpS types which typically experienced relatively frequent fires prior to European settlement, but currently are experiencing infrequent fire during the fire history period; frequency was set to the Fire History Period Length (FHPL). For BpS types that experienced less frequent fire prior to European settlement, a lack of fire during the fire history period would result in setting Fire Frequency to the reference fire frequency which was modeled for that BpS.

   This relationship of Fire Frequency to MFI can be expressed with the following expression:

   If MFI is less than historical fire frequency or MFI is less than FHPL
   Set Frequency to MFI
   Else
   Set Frequency to the maximum of historical fire frequency and FHPL

The Frequency metric is joined to a combined raster of the watershed and BpS. The combined layer is then reclassified to produce a fire frequency that was averaged over each BpS within each watershed for the fire history period. This Fire Frequency raster can be used as the Current Fire Frequency spatial input to the $FRCC_{MT}$. In addition to the Current Frequency raster, a raster based on the MFI intermediate metrics which resulted from the frequency calculation is also be generated.