

Mapping Landscape Fire Frequency for Fire Regime Condition Class

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Abstract—Fire Regime Condition Class (FRCC) is a departure index that compares the current amounts of the different vegetation succession classes, fire frequency, and fire severity to historic reference conditions. FRCC assessments have been widely used for evaluating ecosystem status in many areas of the U.S. in reports such as land use plans, fire management plans, project plans, burn plans, and agency reporting.

The FRCC Mapping Tool (FRCC_{MT}) spatially models FRCC within a Geographic Information System (GIS). Succession classes are available as a spatial input to the FRCC_{MT} from LANDFIRE. The FRCC fire severity spatial input can be generated with the Wildland Fire Assessment Tool (WFAT) which utilizes spatial inputs from LANDFIRE along with weather inputs which are readily available from the Remote Automated Weather Stations (RAWS) Climate Archive at www.raws.dri.edu. At this time, no models have been developed which enable the generation of fire frequency at a spatial scale similar to that of succession class and fire severity.

This research develops and evaluates methods and data which enable users to create spatial fire frequency inputs to the FRCC_{MT}. Fire frequency data being analyzed for inclusion in such a model include LANDFIRE disturbance maps, Monitoring Trends in Burn Severity maps, and local fire history maps. Fire frequency methods and results are presented for case studies of user-specified time periods. We conclude that these methods could be implemented to provide a software tool which can utilize the previously mentioned datasets to produce spatial frequency data which can be utilized as inputs for mapping of FRCC. Additionally, we propose additional metrics which can assist with development of management plans for mitigating severe frequency departure and returning project areas to a state which more closely resembles reference conditions.

Introduction

The precursors to the Fire Regime Condition Class (FRCC) concept have been in existence since the 1990s as indicators of landscape ecological condition and resilience to disturbance (Hann and others 1998; Hann and Bunnell 2001). FRCC was developed as a standardized national approach during the late 1990s. FRCC is a departure index that compares the current amounts of the different vegetation succession classes, fire frequency, and fire severity to historic reference conditions. FRCC assessments have been widely used for evaluating ecosystem status in many areas of the U.S. in reports such as land and fire management plans, National Environmental Policy Documents, project plans, burn plans, and agency accomplishments. FRCC requires a variety of data inputs including the amounts of different succession classes within biophysical settings, estimates of time period fire frequency and severity and associated reference values for historical within the analysis area extent.

The FRCC Mapping Tool (FRCC_{MT}) has been developed under the sponsorship of the USDA Forest Service and USDI Fire Management Agencies. The Wildland Fire Management

Research Development and Applications (WFMRD&A) unit, an inter-agency team, manages the development and applications of this tool and many other wildland fire and fuels decision support tools. The FRCC_{MT} spatially models FRCC within a Geographic Information System (GIS). Succession classes (SClass) are available as a spatial input to the FRCC_{MT} from LANDFIRE. The FRCC fire severity spatial input can be generated from the WFMRD&A Wildland Fire Assessment Tool (WFAT) which utilizes spatial inputs from LANDFIRE along with fire weather inputs which are readily available. At this time, no models have been developed which enable the modeling of fire frequency at a spatial scale similar to that of succession class and fire severity. The only method for determining current fire frequency spatially as an input for the FRCC_{MT} relies on using expert opinion as an input for the Fire Frequency and Severity Editor (FFSE) which is included as part of the FRCC_{MT}.

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

In: Keane, Robert E.; Jolly, Matt; Parsons, Russell; Riley, Karin. 2015. Proceedings of the large wildland fires conference; May 19-23, 2014; Missoula, MT. Proc. RMRS-P-73. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 345 p.

in rare-interval systems (Keane and others 2002). It is important as an ecological measure as the interval between fires determines the subsequent species of plants that may occur, the amount and structure of re-growth, and the amount and kinds of fuel accumulation (Wright and Bailey 1982). These in turn determine, for the next fire occurrence, its probability of ignition and type of fire. Fire frequency is an important factor in measuring resilience as it can determine both the next kind of fire disturbance as well as the ability of the ecosystem to return to its prior functions (Denslow 1985; Holling 1973).

This research develops and evaluates methods and data which would enable users to create spatial fire frequency inputs to the FRCC_{MT} at a similar scale as SClass and fire severity. Fire frequency data being analyzed for inclusion in such a model include LANDFIRE disturbance maps, Monitoring Trends in Burn Severity (MTBS) maps, and local fire history maps. Fire frequency methods and results are presented for case studies of user-specified time periods including a set of historic sub-periods based on the dataset that best captures the fire history within the post-reference period. The goal of this research is to develop a methodology for the determination of fire frequency which could be implemented to provide a software tool. This tool will utilize the previously mentioned datasets to produce spatial frequency data which can be utilized as the fire frequency input to the FRCC_{MT} for mapping of FRCC outputs.

Fire History Data Sources

When calculating wildland fire frequency for Fire Regime Condition Class, the method that users currently have available is to utilize the Frequency and Severity Editor (FFSE) in the FRCC_{MT}. The FFSE allows a user to assign current estimates of fire frequency by Biophysical Setting, creating a Fire Frequency raster which the FRCC_{MT} can utilize as a spatial input. When using the Frequency and Severity Editor, the preferred data source for a study area is a fire atlas of the local management unit. Basing estimates on a fire atlas is more defensible than other data sources, such as fire history field observations and formal fire history research (Jones and Ryan 2012).

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. The Monitoring Trends in Burn Severity (MTBS) program has spatially documented large wildland fires that have occurred beginning in 1984. The LANDFIRE project has produced disturbance layers that include both wildland fire and prescribed fires since 1999. 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).

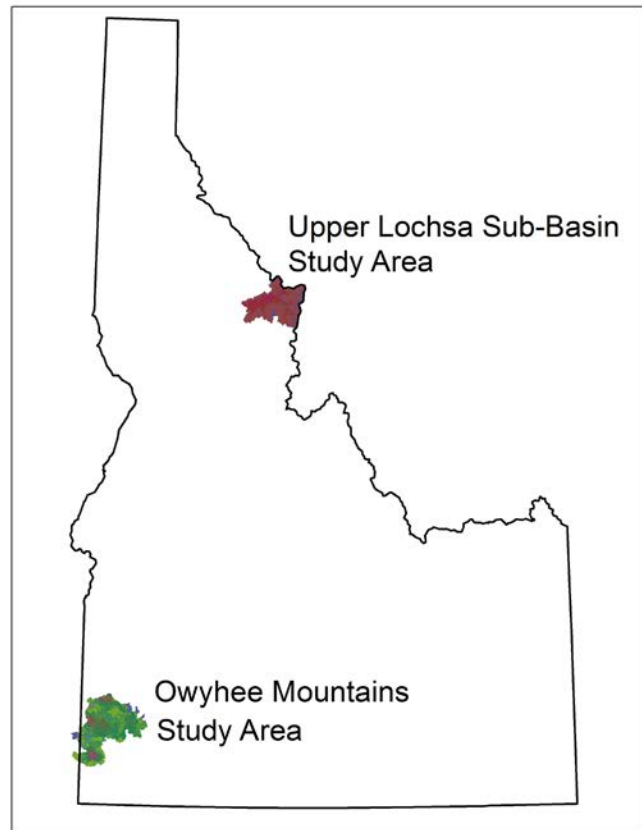


Figure 1—The upper Lochsa River subbasin in northern Idaho is a mountainous region containing subalpine and mountain mesic forests and woodlands. The upper Lochsa subbasin is in the Clearwater National Forest in northern Idaho. The Owyhee Mountains in southwest Idaho consist primarily of xeric montane sagebrush steppe. Most lands in the Owyhee Mountains are administered by the BLM's Owyhee Field Office.

The case studies of the data and methods included two study areas in Idaho. One study area was the upper Lochsa River subbasin in north Idaho, a region consisting primarily of subalpine and mountain mesic forests and woodlands. The other study area was in the Owyhee Mountains in southern Idaho, an area which by contrast is primarily xeric montane sagebrush steppe. The location of both study areas is shown in figure 1.

LANDFIRE Disturbance Data

The LANDFIRE Disturbance data are a set of digital spatial datasets which provide temporal and spatial information related to change to wildland vegetation and fuels across the United States caused by management activities and natural disturbances. Disturbance data were developed using Landsat satellite imagery, local agency-derived disturbance polygons, and other ancillary data (LANDFIRE 2014). These data include attributes which are associated with disturbance year and disturbance type, including both wildland fire and prescribed fire. The LANDFIRE Disturbance data starts with disturbances that occurred in 1999. As of the year of this analysis, 2014, the dataset includes disturbances that occurred through 2010.

The LANDFIRE Disturbance dataset consists of a set of rasters in ArcGRID format, each of which shows at 30-meter resolution the spatial extent of disturbances for a given year. These disturbances include wildland and prescribed fire, mortality due to insect and disease, and harvesting and thinning. In addition, the data indicates the conversion of wildland into housing, commercial and industrial building sites. The LANDFIRE Disturbance rasters can be downloaded from the LANDFIRE website at www.landfire.gov.

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 U.S. and 500 acres in the eastern U.S. 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 both study areas. The fire atlas data from the Clearwater National Forest for the upper Lochsa subbasin includes fire history from 1907 through 2011. The fire atlas data from the BLM for the Owyhee spans from 1962 through 2011. In comparing fire data from local fire history atlases against perimeters recorded in MTBS and LANDFIRE, it was found that the local fire history atlases tended to under-report fires, especially smaller fires.

Fire Frequency Methodology

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 was converted into Fire Occurrence rasters which do not overlap temporally. Both the MTBS and local fire history datasets were vector-based polygons, so methods followed a similar process. The LANDFIRE disturbance rasters required a separate process for creating an associated Fire Occurrence raster.
2. The Fire Occurrence raster from each dataset was then conjoined into a single Fire Occurrence raster.
3. Fire frequency, using the FRCC definition, was then generated from the Fire Occurrence raster.

Conversion of Fire Polygons to a Fire Occurrence Raster

To include either an MTBS or fire atlas shapefile containing fire perimeters, that shapefile must first be converted into a Fire Occurrence raster. This 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 were identified for each given sub-period. Once those date ranges have been identified, only fire perimeters within the sub-period were retained. LANDFIRE Disturbance layers were used for fires from 1999 through 2010. MTBS data was extracted from fire seasons from 1984 through 1998, which was prior to the availability of LANDFIRE data. The fire atlas from the Clearwater National Forest contains fire history for the upper Lochsa study area, recording fire polygons dating back to 1907, allowing the extraction of fire atlas polygons from 1907 through 1983. The fire atlas from the Idaho BLM which includes the Owyhee study area contains fire history data dating back to 1960, allowing utilization of fire atlas polygons from that fire history sub-period.

Conversion of polygons to a raster

Conversion of fire perimeter polygons into a Fire Occurrence raster was accomplished by taking the geometric intersection of the polygons from which a resulting raster indicates how many fire polygons were co-located with each intersection polygon. This can be with the following steps:

1. Obtain the geometric intersection of the fire perimeter polygons. It is assumed that all areas within the fire perimeter polygons were burned. Taking the geometric intersection will produce a polygon layer which contains segmented fire polygons where all the area within a given polygon will have burned the same number of times. For example, assume there are two overlapping fire perimeter polygons corresponding to the A fire and the B fire. This would result in 3 polygons, one polygon containing area within the A fire but not within the B fire, denoted $A \setminus B$, another polygon

containing the area burned by the B fire but not by the A fire, denoted $B \setminus A$ and the intersection of the two fires, denoted $A \cap B$.

2. Create a centroid for each segmented polygon resulting from the geometric intersection.
3. Identify how many fire perimeters each of the centroids are located within.
4. Copy the centroid attributes back to their associated segmented fire polygons.
5. Convert the shapefile with the segmented fire polygons into a Fire Occurrence raster.
6. Set the pixels in the Fire Occurrence raster to 0 where fire did not occur.

The resulting Fire Occurrence raster will show 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.

Conversion of LANDFIRE Disturbance Rasters into a Fire Occurrence Raster

LANDFIRE Disturbance rasters contained a spatial record of the disturbance types including both wildland fire and prescribed fire. Each LANDFIRE Disturbance raster contained the disturbances of a given year. The fire records were extracted from each of the LANDFIRE Disturbance rasters and then conjoined into a single Fire Occurrence raster.

Extraction of fires from LANDFIRE Disturbance rasters

Extracting the spatial record of fire disturbances from a LANDFIRE Disturbance raster was accomplished by reclassifying the raster for fire associated disturbance types. This process was employed on each of the LANDFIRE Disturbance rasters within the set of rasters which cover the fire history sub-period. Extraction of fire disturbances from a LANDFIRE Disturbance raster can be accomplished with the following steps:

1. Export the raster attribute table to a database.
2. Add a "FIRE" column to the table, setting the column based on whether the value in the *DIST_TYPE* column for a row contains the word "fire."
3. Join the database table back to the raster so the FIRE attribute is included in the raster's attribute table.
4. Reclassify the raster to create a Fire Occurrence raster from the LANDFIRE Disturbance raster, resulting in a binary raster showing burned and unburned pixels.

The resulting annual Fire Occurrence rasters showed the spatial distribution of fire occurrence in the study area for the year represented by the corresponding LANDFIRE Disturbance raster.

Conjoining the LANDFIRE annual Fire Occurrence rasters into a single Fire Occurrence raster

A single Fire Occurrence raster was created which represents fire occurrence for the LANDFIRE historic sub-period.

The set of annual Fire Occurrence rasters which were derived from the LANDFIRE Disturbance rasters were conjoined into a single Fire Occurrence raster using a map algebraic add. This Fire Occurrence raster corresponds to the LANDFIRE Disturbance rasters for 1999 through 2010.

Conjoining the LANDFIRE, MTBS and Fire Atlas Fire Occurrence Rasters

A single Fire Occurrence raster was created from the Fire Occurrence rasters that were derived from the LANDFIRE Disturbance, MTBS and Fire Atlas by conjoining the three rasters utilizing a map algebraic add. The resulting Fire Occurrence raster showed 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. The Fire Occurrence raster for the upper Lochsa subbasin is shown in figure 2.

Calculate Frequency from Fire Occurrence

Once the Fire Occurrence raster was created for the complete fire history period, a Fire Frequency raster was derived. In this process, there were additional intermediate rasters that were generated.

Creation of the Fire Frequency raster from the Fire Occurrence raster involved normalizing the Fire Occurrence raster by landscape and for the Biophysical Setting (BpS). The BpS layer was downloaded from LANDFIRE and represented a relatively uniform environment for categorizing vegetation and fire regime. Intermediate fire frequency metrics were calculated for the combination of landscape and BpS.

Normalization of Fire Occurrence by landscape and BpS

For analysis of FRCC, the $FRCC_{MT}$ utilized two spatial inputs for stratifying the study area. The study areas were delineated via a landscape level to allow for a spatial extent of the FRCC analysis to an assessment area which contained a spatial extent of sufficient size to allow for variability in the vegetation and fire regimes. Watershed hierarchies were used to delineate landscapes to achieve this outcome. Study areas were also stratified within the watershed hierarchy by using BpS. These Hydrologic Units (HUC) layer were downloaded from the USDA Natural Resources Conservation Service's Geospatial Data Gateway at datagateway.nrcs.usda.gov. The Fire Occurrence data, stratified by watershed hierarchy and BpS were then combined, producing a single spatial dataset representing Fire Occurrence within landscape and BpS.

Calculation of intermediate metrics

The attribute table of the combined watershed/BpS/Fire Occurrence raster was exported to a database. This database was then queried to derive the intermediate fire frequency metrics, which were calculated for each BpS within each watershed. These calculations were conducted with the following steps:

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

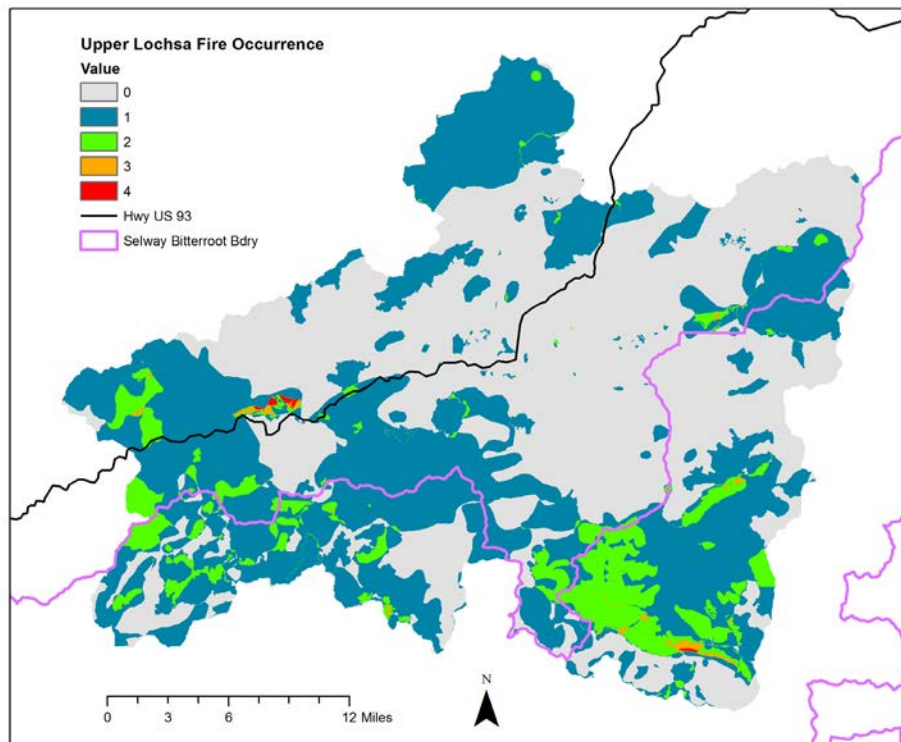


Figure 2—Fire Occurrence raster for the upper Lochsa subbasin for the fire history period from 1907 through 2010. Highway US 93 and the wilderness boundary are shown for reference.

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 reference fire regime (Barrett and others 2010). In BpS types which typically experienced relatively frequent fires during the reference period 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 during the historic reference period 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 reference fire frequency or MFI is less than FHPL

Set Frequency to MFI

Else

Set Frequency to the maximum of reference fire frequency and FHPL

Reclassify landscape/BpS to create Fire Frequency raster

The Frequency attribute from the database was joined to a combined raster of the watershed and BpS. The layer was 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 (figure 3) was then used as the Current Fire Frequency spatial input to the $FRCC_{MT}$. In addition to the Current Frequency raster, rasters based on other intermediate metrics which resulted from the frequency calculation, such as Mean Annual Burned could also be generated.

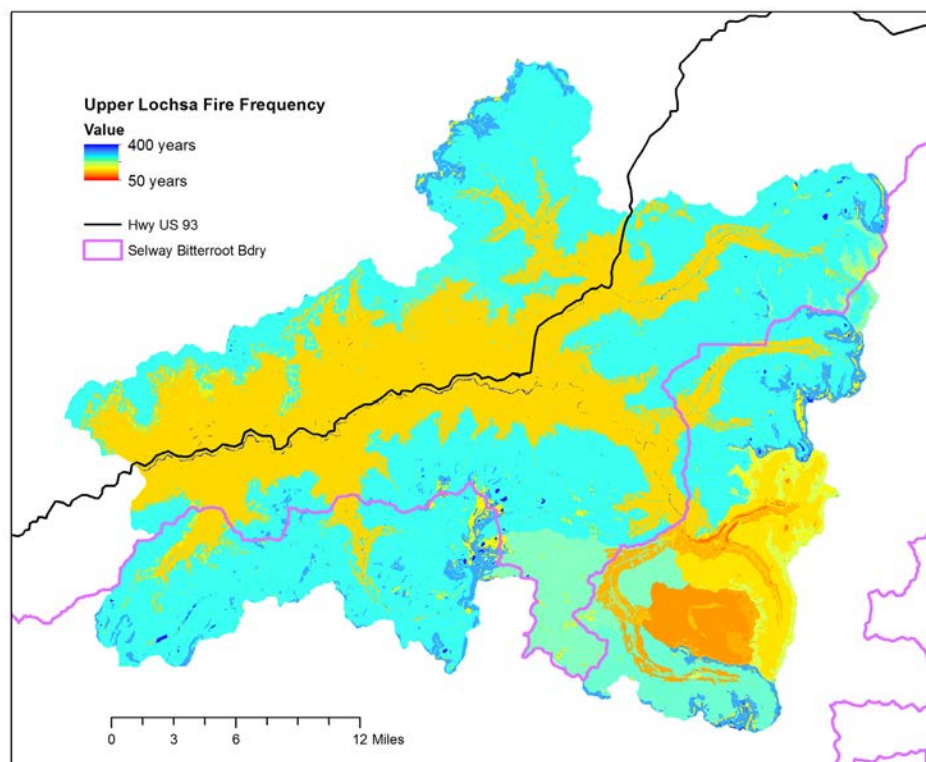
Comparison of Data Sources

In analyzing the upper Lochsa study area, we also compared data from LANDFIRE and MTBS against the local fire atlas data for the overlapping sub-period of the fire history period. This was done to compare local data with LANDFIRE and MTBS approaches. Additionally, we compared these datasets to point-based fire data derived from fire incident reports which was provided by the Clearwater National Forest.

Comparison of MTBS/LANDFIRE Data to the Local Fire Atlas

For the purpose of this comparison, we looked at fire history data from 1984 through 2010, which corresponds to the fire history sub-period for which we have fire history available through a combination of the MTBS and LANDFIRE projects. In selecting data from the MTBS and LANDFIRE projects, LANDFIRE Disturbance layers

Figure 3—Fire Frequency raster for the upper Lochsa subbasin for the fire history period from 1907 through 2010. This raster can be utilized as the Current Fire Frequency spatial input for assessing FRCC with the FRCC Mapping Tool.



were used from 1999 through 2010 and MTBS perimeters were used from 1984 through 1998.

In comparing the area burned between the MTBS/LANDFIRE and the local fire atlas, data from MTBS/LANDFIRE was found to report very similar total acres burned to the acreage reported from the fire atlas for that period. Both, the LANDFIRE/MTBS data and the local fire atlas data indicated about 108,000 acres burned. However, the MTBS/LANDFIRE data indicated that a substantial area had burned more than once; about 2000 acres for MTBS/LANDFIRE versus about 1000 acres from the fire atlas. A visual inspection of both datasets show a higher fire occurrence in the portion of the study area within the portion of the upper Lochsa subbasin which lies within the Selway-Bitterroot Wilderness.

Comparison of Spatial Fire History Data to Point-Based Data

In addition to these fire history data sources, we also looked at a point-based fire history shapefile provided by the Clearwater National Forest which was attributed with date, size class, and acres burned. The point-based fire history data was analyzed for the same fire history sub-period (1984-2010) within the study area. The point-based dataset was found to contain 13 percent more acres burned than recorded by the LANDFIRE/MTBS dataset. MTBS data does not contain record of fires where less than 1000 acres burned. This could account for a significant portion of the difference between acres burned between the two datasets.

Comparison of Frequency from Fire History versus Frequency and Severity Editor

Currently the only method for determining current fire frequency spatially as an input for the FRCC_{MT} relies on using expert opinion as an input to the Fire Frequency and Severity Editor (FFSE) component of the FRCC_{MT}. This tool allows the user to specify a single current frequency for each BpS, from which the tool will create a frequency raster. The disadvantage of this approach is that the BpS is assigned the same frequency in all landscapes across the study area. A comparison of the Frequency raster generated from the MTBS/LANDFIRE period for the upper Lochsa sub-basin as compared to the Frequency raster generated from the editor indicates that this may not be a valid methodology. As indicated in table 1, there is considerable variability in the MTBS/LANDFIRE fire frequency across BpS's between watersheds in the study area. This variability is not surprising considering that part of the study area lies within the Selway-Bitterroot Wilderness Area where management policy emphasizes allowing fire to play its natural role as compared to the rest of the study area which is affected by different management policies.

Management Implications

After the Frequency raster was created using this methodology, the FRCC_{MT} was run using the Frequency raster as its Current Fire Frequency spatial input. The FRCC_{MT} produced a Frequency Departure output raster which was used

Table 1—Comparison of Frequency within Biophysical Settings (BpS)'s between landscapes across the upper Lochsa subbasin, as mapped in Figure 3.

BPS	Name	Size (acres)	Minimum Frequency (years)	Maximum Frequency (years)
1010451	Ponderosa Pine-Douglas Fir	8677	24	28
1010452	Western Larch-Douglas Fir	4912	25	40
1010453	Grand Fir-Douglas Fir-Beargrass	48744	21	69
1010460	Whitebark Pine	26579	26	161
1010471	Grand Fir-Douglas Fir-Western Red Cedar-3	72441	26	80
1010550	Engelman Spruce-Subalpine Fir-4	7920	27	133
1010560	Engelman Spruce-Subalpine Fir-4	275157	25	172
1011400	Green Needlegrass-Idaho Fescue-4	424	24	150
1011590	Black Cottonwood-Narrowleaf Willow-3	8529	28	50
1011600	Black Cottonwood-Narrowleaf Willow-3	413	28	80
1011610	Engelman Spruce-Ladyfern-5	267	19	400
1011660	Douglas Fir-Ninebark-3	469	26	31

to calculate Regime Departure and Condition Class. Based on the Frequency Departure, we then could evaluate which BpS's were departed from their Reference Frequency for each of the watersheds.

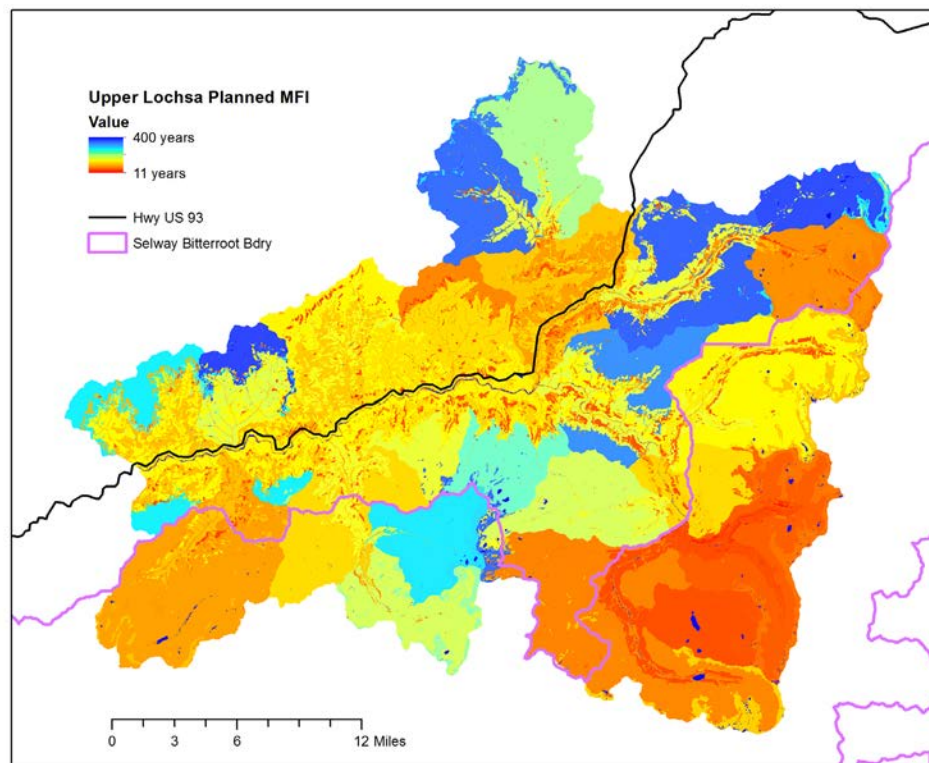
Based on the frequency departure by BpS and watershed, we hypothesized that a plan could be developed to respond to departures caused by a lack of fire or too much fire. One method tested identified how much more of a BpS needs to be burned in a landscape by comparing the Burned Area metric against how many acres needed to be burned within an upcoming planning period to restore a BpS to the amount of burning indicated by the historical fire regime. For example, we assumed that the objective is to restore the BpS to a burn rate which would be within 33 percent of the historical reference frequency (RefFreq) over the next 10 years. We referred

to the 33 percent variance from the historical frequency as a Condition Class Factor (ccFactor). The acreage that would need to be burned in order to achieve this objective was referred to as Planned Area Burned (pAB) which is calculated with the following equation:

$$pAB = (ccFactor(BS * (FHPL + PPL)) - cAB) / RefFreq$$

where cAB is the area that has already burned in the BpS during the current fire history period and PPL is the planning period length.

Once we identified the planned Area Burned, we used that as input to the metrics used to calculate planned MFI and planned Fire Frequency at the end of the planning period. The results indicated that the Planned Fire Frequency raster for the upper Lochsa study area could be mapped (figure 4). This

**Figure 4**—Planned Mean Fire Interval raster for the upper Lochsa subbasin. This MFI raster assumes that the acreage indicated by the Planned Area Burned is successfully burned in order to achieve the objective of returning the BpS to within 33 percent of the acreage that would have been burned under reference conditions during the current fire history period.

planned Fire Frequency can then be used as an input to the $FRCC_{MT}$ to determine the Frequency Departure for the BpS at the end of the planning period.

Conclusion

Fire history data were coalesced from multiple fire history sources with different formats covering different time periods in order to calculate Frequency for a specified time subperiods or averaged for the whole period.

Fire frequency and departure were found to be very useful measures for evaluating the ecological condition and resilience of the fire regime. Using this approach with data readily available we calculated a frequency ecological condition class that can be used independently or as an input to the Regime or $FRCC$ calculations. Condition classes 2 and 3, associated with high departures from historical reference values, would have high potential to have lost or vulnerability to loss of key ecological values, such as native structures and composition and natural disturbance regimes and watershed processes.

We also tested use of the fire frequency data to calculate if fire is trending towards too much fire or lack of fire in comparison to the historical reference frequency. We consider this to be an important metric for evaluation of ecosystem resilience. This Mean Fire Interval Percent Difference (MFIPD) was calculated as follows:

If $MFI < \text{Reference Frequency}$

$$MFIPD = (1 - [MFI / \text{RefFreq}]) * 100$$

Else

$$MFIPD = -1 * ((1 - [\text{RefFreq} / MFI]) * 100)$$

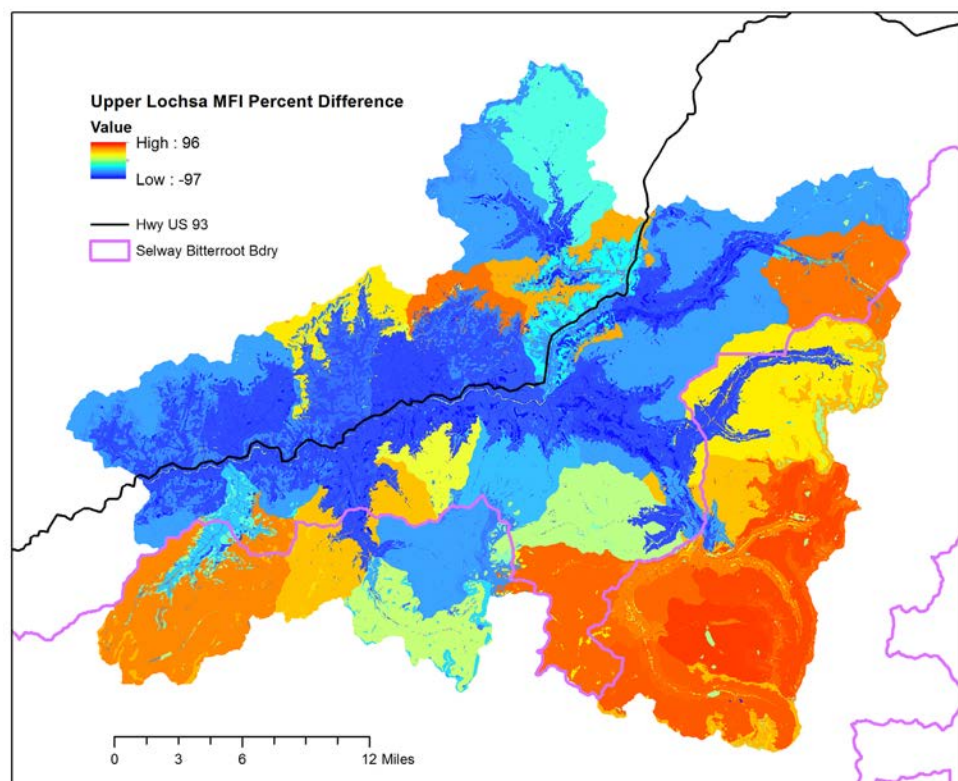
A positive MFIPD indicated that fire was abundant (in other words, there is too much fire). A negative MFIPD indicated that fire was deficient (in other words, there is not enough fire). An MFIPD raster for the upper Lochsa sub-basin is shown in figure 5. Values determining fire to be too abundant would indicate a lack of resilience as plant species would not have time for adequate succession or growth and development to achieve a complete cycle of functioning processes. In contrast, values portraying a deficiency of fire indicate a lack of resilience for return of fire-adapted species that are time or fire disturbance type dependent.

The results from this study indicate that use of the $FRCC_{MT}$ Fire Frequency and Severity Editor may be much too coarse for useful management interpretations. The data in the upper Lochsa study area indicated that there was far too much variability in fire occurrence between watersheds to assume a single value would accurately reflect the current fire frequency for a BpS across all watersheds.

We found that small fires can substantially impact the Frequency within a BpS within a watershed. Analysis of the upper Lochsa data showed that exclusion of small fires from the historical record may have accounted for a loss of spatial record for over fifteen percent of the acres burned. This loss of historical fire extent is especially important as small fires accounted for a greater spatial distribution of fire across the study area than was found for large fires. This tendency to under-report small fires has been reported in other studies as a common problem with local fire history atlases (Morgan 2014).

Results from the upper Lochsa study area indicate that a large wildland fire or many small fires can enable managers to approach reference Mean Fire Interval for a BpS/watershed

Figure 5—Mean Return Interval Departure raster for the upper Lochsa sub-basin. This MFID raster indicates how abundant or deficient fire is within a BpS. Negative MFID indicates fire deficiency (not enough fire), positive MFID indicates abundance.



where fire occurrence has been in deficit. The large fires allowed to burn in the Selway-Bitterroot Wilderness Area (in the southeast corner of the study area) had a dramatic effect on increasing Fire Occurrence and as a result reduced Frequency Departure. Managing for additional fire activity over the next 10 years could increase this positive impact on Fire Frequency Departure and thus improve the overall Fire Regime Condition Class.

The methodology employed to spatially integrate the data sources and calculate fire frequency was complex. This process would be error prone if performed manually due to the numerous geoprocessing steps and calculations performed. Thus, it would be impractical for the majority of the analysts to manually perform the steps to map current frequency and departure. In order to provide efficient and confident results these methodologies should be automated. A large number of layers were downloaded and analyzed as inputs to calculate FRCC with the FRCC_{MT}. Our analysis for generating a fire frequency input for the FRCC_{MT} required the downloading of 13 layers from LANDFIRE and MTBS. Creating a Severity input raster using WFAT required downloading 9 layers. The FRCC_{MT} required the Landscape, BpS and SClass layers be downloaded. Consequently, the complete analysis of all inputs and outputs for mapping FRCC required a total of 25 data layers. We recommend implementing these methodologies as a web application along with migrating the rest of the FRCC_{MT} and the WFAT. Hosting the tools on the web would facilitate updates to the data inputs and methodologies, increase efficiency of downloading LANDFIRE data, and ensure users adequate computing resources for calculating vegetation, fire frequency, and fire severity departures and condition along with the composite FRCC.

In summary, we conclude with the following three points.

1. Recent historic and current fire frequency data generated from MTBS, LANDFIRE, and local fire atlases allowed implementation of the FRCC Guidebook methods for mapping fire frequency at equivalent scales as currently available for vegetation and fire severity inputs.
2. The recent historic and current fire frequency maps were highly useful in evaluating ecological condition, resilience to disturbance, and building of scenarios to achieve fire and fuel management objectives.
3. Downloading, analysis, and modification of FRCC input data to produce reliable outputs was a complex process. Integration of this process into a web-based decision support system would substantially increase efficiency, and application of these important ecological measures within the fire, fuels, and vegetation management community.

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