Modifying LANDFIRE Geospatial Data for Local Applications

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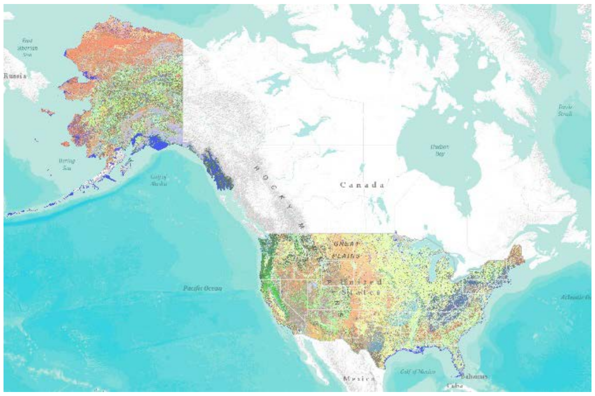

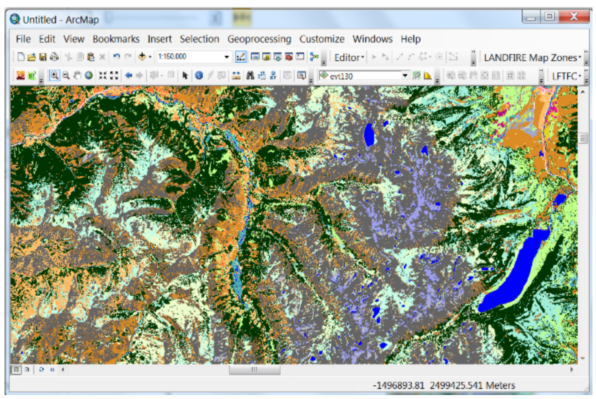

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Introduction

The LANDFIRE Program provides “wall-to-wall” geospatial data of vegetation, wildland fuel, fire regime, disturbance, and topographic characteristics for the United States (Rollins 2009). LANDFIRE data are often an excellent choice for wildland fire and land management planning applications due to their consistent mapping methodologies across land ownership boundaries and relevancy to common conservation and land management questions. LANDFIRE data are distributed free of charge through the Program’s website at www.landfire.gov.

This guide will focus on LANDFIRE data for the conterminous United States, Alaska, and Hawaii. A subset of LANDFIRE data products is available for the Pacific and Caribbean U.S. insular areas; however, the mapping methodologies for these areas vary substantially enough from those for the conterminous U.S., Alaska, and Hawaii that we do not include discussion of these data in this version of the guide. We also focus primarily on LANDFIRE versions 1.0.5 (LANDFIRE 2001) through 1.3.0 (LANDFIRE 2012) as some major changes to mapping methodology occurred between version 1.0.0 (LANDFIRE National) and LANDFIRE 2001.

Although developed for sub-regional to national-scale planning applications, the utility of LANDFIRE data at finer scales has been demonstrated. The data are commonly applied on active wildland fire incidents (Noonan-Wright et al. 2011) and in landscape-level land management planning (Helmbrecht et al. 2012, Price et al. 2012, Scott et al. 2012, Tuhy et al. 2010). However, the applicability of LANDFIRE data at finer scales varies by the data product in question, its intended use, and location of interest. The LANDFIRE Program states that:

> *“Managers and planners must evaluate LANDFIRE data according to the scale and requirements specific to their needs (for example, habitat requirements for the species being considered or requirements by community leaders and interagency partners).… It is the responsibility of the user to be familiar with the value, assumptions, and limitations of LANDFIRE products”* (USFS 2015).

It is within this context that we present this guide, with the purpose of providing direction on the critique and modification of LANDFIRE geospatial data products for local applications. This guide builds upon previous work on this topic by others (Stratton 2006, 2009; The Nature Conservancy 2011a; The Nature Conservancy 2011b; The Nature Conservancy 2013). It is not so much a “cookbook” or “how-to” guide, as the specifics vary greatly by data product, intended use, scale, and location. Rather, we present primary considerations for using and modifying the data for use in local applications and provide examples and demonstrations of available tools and methods for completing common critique and modification tasks.

This guide is presented in seven chapters:

Chapter 1 provides a brief overview of LANDFIRE data products; discusses general considerations of scale, accuracy, and resolution in the critique of LANDFIRE geospatial data; and provides examples of common reasons for modifying LANDFIRE geospatial data.

Chapter 2 presents a conceptual framework for critiquing and modifying geospatial data, emphasizing the importance of framing analysis objectives and an iterative approach.

Chapter 3 describes the LANDFIRE disturbance data mapping process and discusses considerations specific to data currency, disturbance causality, and modifying data to reflect changes due to new disturbances.

Chapter 4 defines LANDIFRE potential and existing vegetation data products; describes the LANDFIRE vegetation mapping process; and discusses considerations specific to application of the NatureServe Ecological Systems classification, map zone boundaries, and succession class mapping rules.

Chapter 5 defines LANDFIRE fuel data products; describes the LANDFIRE fuel mapping process; and discusses considerations specific to map zone boundaries, application scale, disturbance updates, and modeling.

Chapter 6 describes the LANDFIRE vegetation dynamics models and their role in developing fire regime and vegetation departure products and discusses considerations specific to the integrated nature of LANDFIRE vegetation products, knowledge uncertainty, map zone boundaries, differences between data versions, and conducting local vegetation departure analysis.

Chapter 7 presents two interpreted examples of critiquing and modifying LANDFIRE data for local applications. The first example focuses on using LANDFIRE data for wildfire hazard analysis in the Rogue Basin of southwest Oregon. The second example focuses on using LANDFIRE data for vegetation departure analysis in the southern Sierra Nevada Mountains.

Chapter 1: Background

LANDFIRE Product Overview

LANDFIRE produces more than 20 geospatial data layers, a suite of vegetation dynamics models representing pre-Euro-American settlement vegetation conditions, and databases with vegetation plot and management activities information. The geospatial data, which are the focus of this guide, cover all lands in the United States and are developed using methods that utilize Landsat imagery, plot data, and biophysical gradient modeling (Rollins 2009). The mapping methodology is generally consistent by version across all regions of the country. LANDFIRE periodically updates its data products to incorporate changes over time (Nelson et al. 2013, Table 1).

Table 1: Comparison of LANDFIRE versions 1.0.0 (LANDFIRE National) through 1.3.0 (LANDFIRE 2012).

LANDFIRE Version	Currency	Distribution Date	Version Information
National (1.0.0)	Circa 2001	2008	The first full iteration of LANDFIRE data based on Landsat imagery from 1999-2001.
2001 “Refresh” (1.0.5)	Circa 2001	2011	Enhanced National by improving biophysical setting and existing vegetation type, cover and height mapping.
2008 “Refresh” (1.1.0)	Circa 2008	2011	Updated 2001 products for disturbance and succession. Landsat 1984-2008 imagery analyzed for change.
2010 (1.2.0)	Circa 2010	2013-14	Products updated for disturbance and succession. Landsat 2007-2011 imagery analyzed for change. Refined urban, agriculture, and wetlands mapping.
2012 (1.3.0)	Circa 2012	2014-15	Products updated for disturbance and succession. Landsat 2010-2013 imagery analyzed for change.

LANDFIRE geospatial data can be divided into five primary categories: vegetation, wildland fuels, fire regime, disturbance, and topography (Table 2). The vegetation data layers characterize both existing and potential vegetation type, vegetation structure, and vegetation development stage, and are primary inputs for developing other data layers. The wildland fuel data layers depict surface and canopy fuel characteristics that are inputs to various geospatial fire modeling systems. The fire regime data layers estimate the fire frequency and severity prior to European-American settlement as well as the current condition of the vegetation within the context of the historical disturbance regime. The disturbance data layers depict landscape changes that result from natural disturbances (e.g. wildfires and hurricanes) and management activities (e.g. prescribed fire and timber harvest), and are used to update the vegetation and fuel data layers over time (Nelson et al. 2013). Finally, the topographic data layers are required inputs to common geospatial fire behavior modeling systems and are used as base data for developing other LANDFIRE data layers. Modification of topographic data (elevation, slope, and aspect) is uncommon and therefore not discussed in this guide.

Table 2: LANDFIRE data products organized by data category.

Data Category	Abbreviation	Data Products
Vegetation	EVT	Existing Vegetation Type
	EVC	Existing Vegetation Cover
	EVH	Existing Vegetation Height
	SCLASS	Succession Class[a]
	ESP	Environmental Site Potential
	BpS	Biophysical Setting
	--	Vegetation Dynamics Models[b]
	LFRDB	LANDFIRE Reference Database[c]
Fuel	FBFM13	13 Fire Behavior Fuel Models
	FBFM40	40 Fire Behavior Fuel Models
	CFFDRS	Canadian Forest Fire Danger Rating System (AK only)
	FCCS	Fuel Characteristics Classification System Fuelbeds
	FLM	Fuel Loading Models
	CC	Forest Canopy Cover
	CH	Forest Canopy Height
	CBD	Forest Canopy Bulk Density
	CBH	Forest Canopy Base Height
Fire Regime	FRG	Fire Regime Groups
	MFRI	Mean Fire Return Interval
	PLS	Percent Low-severity Fire
	PMS	Percent Mixed-severity Fire
	PRS	Percent Replacement-severity Fire
	VCC	Vegetation Condition Class[d]
	VDEP	Vegetation Departure[e]
Disturbance	DYEAR	Disturbance 1999-2012
	FdistYEAR	Fuel Disturbance
	VdistYEAR	Vegetation Disturbance
	Events	Public Events Geodatabase[f]
Topography	ASP	Aspect
	DEM	Elevation
	SLP	Slope

[a]LANDFIRE groups succession class with its fire regime datasets because it is used to assess current vegetation condition, but in this guide it is grouped with the vegetation datasets because it is created from a compilation of existing vegetation datasets.
[b]The Vegetation Dynamics Models are non-spatial products used as primary inputs for mapping the fire regime datasets, to provide rulesets for mapping succession classes and as an ancillary data source for mapping existing vegetation type, biophysical settings and fire behavior fuel models.
[c]A database with geo-reference plot information used for mapping the vegetation datasets.
[d, e]Vegetation condition class and vegetation departure were not created for LANDFIRE 2010.
[f]A geo-referenced collection of disturbance and management information used to create the disturbance datasets.

The remainder of this chapter presents general considerations about the critique and modification of LANDFIRE geospatial data. Subsequent chapters will provide greater detail about specific considerations in the vegetation, fuels, fire regime, and disturbance categories.

Considerations of Scale

A primary consideration when evaluating a geospatial data layer is its scale. Traditionally map, or cartographic, scale is defined as the mathematical relationship between a given feature on a map and that same feature on the ground. For example, a typical topographic map from the U.S. Geological Survey's 7.5-minute quadrangle series has a map scale of 1 to 24,000 (1:24,000) meaning that one map unit is equivalent to 24,000 of the same units on the ground. Geospatial data do not have a map scale in the traditional sense. A geographic information system (GIS) stores the exact coordinates of every feature in a geospatial data layer, allowing users to zoom in and out on the monitor to view data at nearly any map scale, regardless of the precision of the underlying source data. This does not mean that geospatial data do not have a scale; rather, the scale of geospatial data may be difficult to discern.

In a more general sense scale may be defined as the spatial (or temporal) dimension of an object or a process, and is characterized by grain and extent (Turner et al. 2001). Grain is the finest level of resolution in geospatial data. For raster data, grain refers to cell size and for polygon data (i.e., vector data), grain refers to the minimum mapping unit. LANDFIRE raster data have a 30m x 30m cell size—that is, each data cell, or pixel, represents a 900m^2 (approximately 0.22 acre) area on the ground. LANDFIRE data therefore have a 30-meter spatial resolution, or grain size. However, LANDFIRE data are not intended to be accurate or useful at the extent of an individual pixel or small group of pixels. The scale at which LANDFIRE data are applicable varies by product, intended use, and the location of interest.

With geospatial data there are no concrete rules that specify the required scale for a given application. Different analyses require data at different scales. For example, the scale needed to identify threatened and endangered species habitat is different than the scale needed to distinguish forests from grasslands. The critical question is, are the data good enough to meet the analysis needs? Evaluating the data accuracy and resolution requirements of your analysis will help answer this critical question.

Considerations of Accuracy and Resolution

Evaluating the accuracy and resolution of LANDFIRE data will help determine its suitability for a given use. Two types of accuracy to evaluate are **positional accuracy**, or the ability of the data to reflect the true or accepted geographic location of features in space, and **content accuracy**, or the agreement between mapped units and the true or accepted value of those units. Likewise, evaluation of resolution includes **spatial resolution**, or the amount of ground area represented by a pixel, and **thematic resolution**, or the level of detail in the classification of map units. Issues with accuracy and resolution are not mutually exclusive—problems with one may result in problems with the other. Ultimately, the goal of understanding these issues is to evaluate the strengths and weaknesses of a geospatial data layer to determine its suitability for a particular analysis. Next we discuss considerations of accuracy and resolution relevant to LANDFIRE data.

Positional Accuracy

Positional accuracy refers to the ability of the data to reflect the true or accepted geographic location of features. There is little the end user of LANDFIRE data can do to improve issues of positional accuracy. Boundaries or distinctions between feature types (e.g., vegetation types) may not be precisely located solely due to the raster format of LANDFIRE data. The spatial resolution of raster data has a direct effect on positional accuracy: the larger the cell size the less accurate the location (Figure 1). However, these should be minor issues if applying LANDFIRE data at an appropriate scale, one in which the data meet the analysis needs. It is also worth noting that vector data, such as the LANDFIRE event polygons, and plot data from the LANDFIRE Reference Database, are not immune to error in the location of features. Issues of positional accuracy may arise due to errors in source data, precision of field measurements, or errors in data entry.

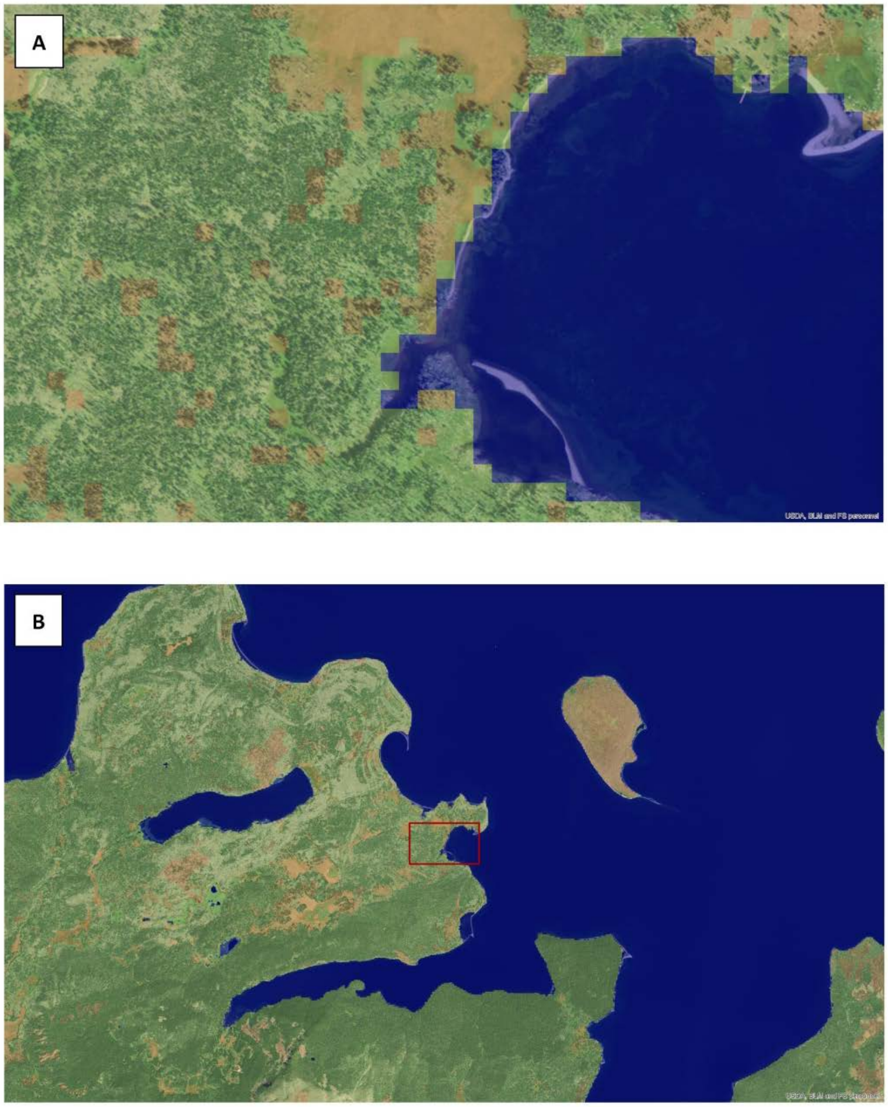


Figure 1. An example of how the spatial resolution of raster data has a direct effect on positional accuracy. LANDFIRE 30-meter resolution data does not precisely depict the shoreline or the boundary between grass (yellow shade) and forest (green shade) when viewed at a small extent (A), but at a broader extent (B), these differences are less apparent and less significant. The red rectangle in panel B shows the extent of panel A.

Content Accuracy

Content accuracy refers to the agreement between mapped units and the true or accepted value of those units. In other words, are the pixel values correct? There is much that can be done by end users of LANDFIRE data to improve issues of content accuracy based on local knowledge, additional data sources, and an understanding of the LANDFIRE data development process. This is the primary focus of this guide. Different types of errors that may affect content accuracy are described next.

Map Unit Errors

Errors in map unit assignments in LANDFIRE data may arise through errors or limitations in remote sensing data, field plots, statistical modeling, processing logic, or a combination of these and other factors. Due to variation in data sources, this error is typically not systematic geographically. For example, the abundance and quality of plot data is inconsistent across the U.S., and cloud-free imagery is more difficult to acquire in certain areas of the country (e.g., Alaska) than others.

Data Currency Errors

One of the most obvious sources of error in vegetation and fuel data is the currency, or age, of the data. Vegetation and fuels change over time due to disturbance and vegetation growth. Disturbance may include the development of previously undeveloped land, natural disturbances, such as windthrow or wildfire, and management activities such as forest thinning or prescribed fire. Vegetation growth over time may result in changes to species composition, structure, and associated dead wood and surface matter. LANDFIRE updates its products accounting for both disturbance and vegetation growth every two years (Nelson et al. 2013), but by the time the data are delivered to the user, they are typically three or more years out-of-date. For example, LANDFIRE 2010 existing vegetation and fuel data were not available for the northwest and southwest United States geographical areas until May 2013.

The importance of updating for these temporal changes should ultimately be determined by the analysis objectives, but the need will also be influenced by the geography and vegetation dynamics of the analysis area. In areas where disturbance is uncommon or where vegetation growth is slow, less frequent updating will be required than in areas that experience frequent disturbances or rapid vegetation growth. For example, vegetation and fuel maps likely need more frequent updating in the south-eastern United States where vegetation growth is more rapid and human and natural disturbances are more frequent than in the desert portions of the southwest. In more mesic life zones, such as mid-elevation forest, the geospatial data layers likely need more frequent updating than in drier low-elevation shrub or grassland zones. Even within local areas there are typically management areas with higher wildland fire or other disturbance activities that require updating as compared to adjacent areas with low activity. Other factors to consider when assessing data currency are the type and size of disturbances that need to be reflected in the data to meet analysis objectives.

Processing or Logic Errors

In some cases, content accuracy issues are introduced during data processing. Unintentional or accidental errors may be difficult to find and correct, but a common source of content error in LANDFIRE products is the result of applying generalized mapping rule sets—a pixel's value is determined by a combination of values from other data as specified in a rule. For example, a rule may assign fire behavior fuel model TU5 (Very High Load, Dry Climate Timber-Shrub), when vegetation type equals mesic mixed conifer and canopy cover is less than 60%. Rule sets are developed and applied at the map zone level (Figure 2). While these rules may be appropriate at the scale of an entire map zone (LANDFIRE map zones range between 12 and 60 million acres in size in the conterminous U.S. and Alaska; Hawaii is a single map zone of 4 million acres), they may need to be refined for application at finer scales. In other words, the "best fit" for an entire map zone may be a compromise between different parts of the map zone. There are also often inconsistencies in mapping rules between adjacent map zones resulting in an "artificial edge" in the data. Many analysis areas often extend across two or even three map zone boundaries. On the ground these changes would start gradually near the boundary between map zones displaying continuous change across the boundary. However, accurately mapping this type of gradual transition is very difficult to achieve in a large national mapping program such as LANDFIRE.

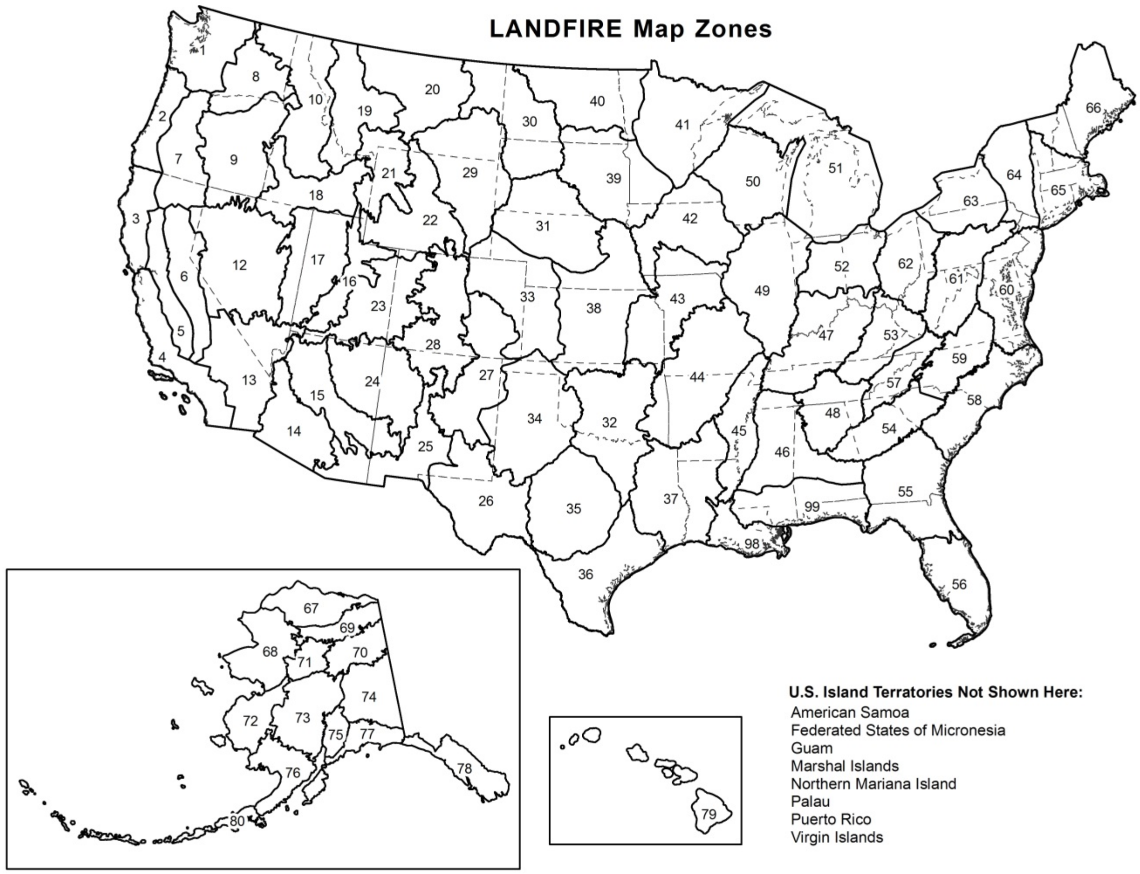


Figure 2. LANDFIRE map zones. There are 80 LANDFIRE map zones across the continental U.S., Alaska, and Hawaii, ranging in size from 4 to 60 million acres.

Content error may also arise due to incomplete knowledge and uncertainty. For example, LANDFIRE's pre-Euro-American fire frequency and severity data are created using a lookup table that links a biophysical setting with the results of a model used to simulate vegetation dynamics and estimate the mean fire frequency and fire severity distribution. The models are created using the best available literature and expert knowledge, but for many biophysical settings, the available information is far from complete. For example, there is considerably more information available to create vegetation dynamics models for biophysical settings that have economic value (e.g. productive forests) than biophysical settings that are rare or traditionally have had little economic value (e.g. arid shrublands; Blankenship et al. 2012). Greater uncertainty about historical fire regime characteristics is also associated with biophysical settings where evidence of historical fires is sparse, non-existent, or just harder to acquire, such as in stand-replacement or very long-interval fire regimes.

Spatial Resolution

As mentioned above, the spatial resolution of raster data is defined as the amount of ground area represented by a pixel. LANDFIRE data are based on Landsat satellite imagery, which have a 30m x 30m pixel size. In other words, each individual pixel represents an area of 30m x 30m, or $900m^2$ (about .22 acres), on the ground.

Spatial resolution can be adjusted if necessary to meet analysis objectives. Decreasing spatial resolution by increasing pixel size (e.g., resampling 30m resolution data to 270m resolution) is sometimes done to: reduce processing time for computationally intensive analyses; decrease file storage space requirements; speed up display time; and/or, reduce the "pixelated" look of a map by absorbing isolated cells into larger patches. While it is possible to adjust resolution the other way, that is to change from coarser to finer resolution, greater map detail can only be achieved if finer resolution geospatial data are incorporated into the resampling process. That is, resampling to a finer resolution without additional finer-scale information gives a false sense of accuracy (see sidebar).

Resampling Raster Data Layers

Resampling is the process of changing the resolution of a dataset. Raster data may be made coarser by aggregating adjacent pixels. Some users of LANDFIRE data who perform national summaries of the data have resampled LANDFIRE grids from 30m to 270m. At this broad extent, resampling may have little impact on the results but can greatly increase computer processing efficiency.

Resampling to a finer resolution is sometimes referred to as downscaling and is often associated with the process of obtaining local level climate data from global climate models. Resampling to a finer resolution is possible using the resample techniques available in ArcGIS, but these techniques will not change the accuracy of the underlying data.

There are several resampling methods available in ArcGIS software, and the resampled raster values will differ depending on the method used.

Thematic Resolution

Thematic resolution refers to the level of detail in the map units. The thematic resolution of LANDFIRE data varies by data product. The most common reason that an end user of LANDFIRE data might change thematic resolution is to ensure that the level of detail in the map units aligns with the level of detail needed to achieve the analysis objectives.

Thematic resolution can be changed to achieve either coarser or finer map units by grouping or splitting map units respectively. Grouping map units is accomplished by aggregating similar map units or by choosing a higher or coarser level within a classification hierarchy (Table 3). One advantage of grouping map units is that it may improve the content accuracy because fewer and more broadly defined units can be mapped, thus minimizing potential error. Splitting map units to achieve higher thematic resolution requires more detailed ancillary data such as maps, plots, higher resolution imagery, or other geospatial data that can be used to distinguish units at a finer level than the original geospatial data layer.

Table 3. Hierarchy of LANDFIRE biophysical setting and existing vegetation type map units. Users can choose the level that best fits their needs or create a hybrid classification by aggregating units. Note that the Society of Americana Foresters and Society of Range Management map units that are provided in the existing vegetation type data layer attribute table is for reference only. This “cover type based” map unit classification is not equivalent to the NatureServe ecological systems classification used by LANDFIRE (see Chapter 4).

Data Layer	Map Unit Level	Example
Biophysical Settings	BpS Name	Central Mixed Grass Prairie
	Group Name	Bluebunch Wheatgrass-Big Bluestem-Little Bluestem-2
	Group Vegetation	Grassland
Existing Vegetation Type	EVT Name	Laurentian-Acadian Northern Hardwoods Forest
	System Group Physiognomy	Hardwood
	System Group Name	Yellow Birch-Sugar Maple Forest
	Society of American Foresters & Society of Range Management Cover Type	SAF 27: Sugar Maple
	National Vegetation Classification System Physiognomic Order	Tree-dominated
	National Vegetation Classification System Physiognomic Class	Closed tree canopy
	National Vegetation Classification System Physiognomic Subclass	Deciduous closed tree canopy

Reasons for Modifying LANDFIRE Data

The above considerations should be helpful in determining whether LANDFIRE data are appropriate for specific objectives and whether modifications are necessary. LANDFIRE geospatial data are commonly modified for the following reasons:

1. update for landscape changes that have occurred since the LANDFIRE version,
2. calibrate to local data and knowledge,
3. improve the thematic agreement (accuracy),
4. change the spatial or thematic resolution (e.g. lump or split map units),
5. modify the map unit classification,
6. create additional data versions that reflect temporal variability (e.g. peat soils being available for burning in drought situations, or exotic annual grasses being present in wet years but not dry years),
7. facilitate comparative analysis by creating data versions (e.g. analyzing pre- and post-treatment effects or comparing treatment alternatives),
8. analyze future conditions (e.g. modifying data to represent future conditions under a climate change scenario).

Conclusion

This chapter provided an overview of LANDFIRE data products, general considerations for critiquing LANDFIRE geospatial data products, and a list of common reasons why these geospatial data are modified for local applications. LANDFIRE's suite of products provides a rich set of data that have proven useful for addressing sub-regional, regional, and national level land management issues and research questions (e.g. Aycrigg et al. 2013, Cochrane et al. 2012, Reeves and Mitchell 2011, Swaty et al. 2011, Zhu et al. 2010). Through proper critique and modification by local natural resource and geospatial professionals, LANDFIRE data may also be appropriately applied to finer-scale, local applications. (e.g., Helmbrecht et al. 2012, Price et al. 2012, Scott et al. 2012, Tuhy et al. 2010). The importance of issues and the time and effort spent addressing them should be determined by the analysis objectives.

Chapter 2: Framework for Data Critique and Modification

This chapter presents a five-step conceptual framework for data critique and modification (Figure 3). The framework begins with defining objectives. Having a clear understanding of objectives will provide a foundation for the remaining steps of the framework. The process is iterative, as findings in one step of the framework may require reevaluation of a previous step. The framework is meant to be flexible and some steps may be combined, depending on the analysis objectives, processes being performed, and experience of the analyst. Certain tools may facilitate the integration of steps. For example, the LANDFIRE Total Fuel Change tool (LFTFCT 2011) allows the analyst to critique, modify, and analyze certain aspects of fuel mapping simultaneously. The framework is typically applied by a team, wherein specialists with expertise in various disciplines (e.g., fire/fuels, silviculture, ecology, and GIS) are involved in the process.

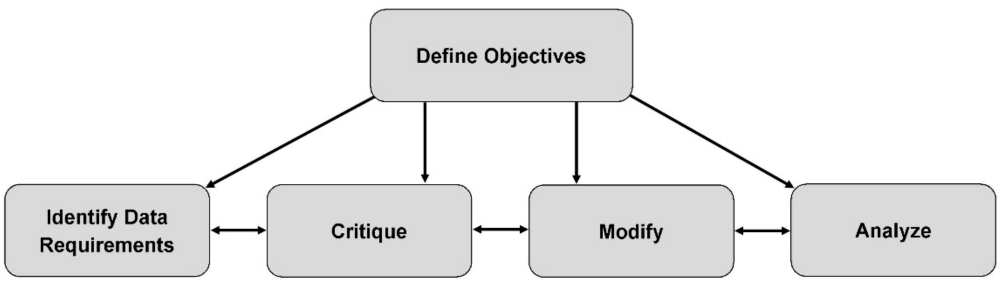


Figure 3. A conceptual framework for data critique and modification. The five-step framework begins with defining clear project objectives. The objectives will dictate the data requirements, influence the type of critique performed, dictate the types of modifications that are needed and determine the analysis performed. The framework is meant to be flexible and in some cases the process may be iterative.

Define objectives

The first step in the data critique and modification process is to define the team's objectives. Clear objectives will be a guiding principle for every other step in this process. For a given analysis determine what is needed from the data (and why), and its intended use. Defining objectives will help determine the data used, the landscape extent, the type of critique to do, and the type and level of modifications necessary.

Identify data requirements

With clear objectives in mind, the next step is to identify the data required to achieve those objectives. For example, if the objective is to assess vegetation departure from a historical reference condition, data is required that characterizes both the historical and current vegetation condition. If the objective is to assess potential wildland fire behavior, data is required that characterizes the fuels and topography of the area of interest.

As will be discussed in subsequent chapters, it is important to understand the linkages among LANDFIRE datasets, as well as the dataset creation method. Resolving issues with data that are mapped using a rule-based methodology, such as fire behavior fuel model or succession class, may require critiquing the data from which those data are derived, such as vegetation type, cover, and height or biophysical setting, thereby increasing the data requirements.

Critique

After identifying data requirements, the critical question is: are the data are good enough to meet the analysis objectives? Data need not be perfect to be useful. Ask what the important characteristics of the data are, and answer this question being mindful of the considerations discussed in Chapter 1. For the given objective: is the scale appropriate, are the data current, are the map units appropriate, and is the spatial resolution (pixel size) too coarse, or too fine? This is an iterative step; the critique may identify the need for additional data and that data will also need to be critiqued. For example, if the data are obsolete due to a recent disturbance, and that disturbance needs to be represented in the data to meet the objectives, then acquire and critique the disturbance data as it will be used to update the original data set.

Modify

Modification of data is the technical step and where GIS skills are mandatory. Subsequent chapters will provide examples of methods for conducting common modification tasks. This is also an iterative step. After modifying the data, critique it once again to be sure the desired result is achieved.

Analyze

The type of analysis performed is determined by the analysis objectives. Common analyses with LANDFIRE data include fire behavior modeling, vegetation departure assessment, and comparative analysis between land management alternatives. It is not uncommon for the results of a particular analysis to reveal data issues or requirements overlooked the first time through the framework. This step may be integrated with the previous step depending on both the analysis type and the experience of the analyst (Chapter 7).

Conclusion

This chapter presented a conceptual framework for critiquing LANDFIRE data for use in local applications. The following chapters discuss specific considerations for critiquing and modifying data from four of the five LANDFIRE data categories: disturbance, vegetation, fuels, and fire regime. Modification of topographic data (elevation, slope, and aspect) is uncommon and therefore not discussed in this guide; however, know that errors may still exist in these data. Having a thorough understanding of the assumptions and limitations of the data is of primary importance in data critique. Therefore, each of the following chapters begins with an overview of how LANDFIRE develops the data products of each category. Next are primary considerations for critiquing the data in each category and examples of why these considerations are important to local applications. Chapter 7 introduces common tools and techniques used for critiquing and modifying LANDFIRE data through interpreted examples.

Chapter 3: Disturbance

Landscape change due to planned and unplanned disturbances is continuously occurring across the United States. Updating LANDFIRE geospatial data for recent disturbances to vegetation and fuels is therefore a common modification task users of LANDFIRE data will encounter: this discussion of data critique and modification considerations thus begins with the disturbance data category. Additional considerations about updating for disturbance as it pertains specifically to vegetation, fuels, and fire regime data will be discussed in subsequent chapters.

LANDFIRE Disturbance Mapping Process

LANDFIRE maps the location, extent, type, and severity of both planned and unplanned disturbances. These data are used for determining vegetation transitions over time, and subsequently updating vegetation and fuel data products. As of LANDFIRE version 1.3.0 (LANDFIRE 2012), yearly geospatial disturbance data are available from 1999 through 2012. The yearly disturbance data are also compiled into two composite disturbance data layers—vegetation disturbance and fuel disturbance—representing disturbances occurring over the previous ten year time period. A time-since-disturbance attribute is recorded in the composite disturbance layers (Figure 4).

Yearly Disturbance Value Attribute Table

Rowid	VALUE *	COUNT	DIST_YEAR	DIST_TYPE	TYPE_CONFI	SEVERITY	SEV_CONFID	SOURCE1	SOURCE2	SOURCE3	SOURCE4	
3	13	13953	2009	Wildfire	High	Medium	High	MTBS				MTBS mapped wildfire.
4	14	6430	2009	Wildfire	High	High	High	MTBS				MTBS mapped wildfire.
5	15	156	2009	Wildfire	High	Increased Green	High	MTBS				MTBS mapped wildfire.
6	21	711	2009	Wildfire	High	Unburned/Low	High	BARC				BARC mapped wildfire.
7	22	94	2009	Wildfire	High	Low	High	BARC				BARC mapped wildfire.
8	23	32	2009	Wildfire	High	Medium	High	BARC				BARC mapped wildfire.
9	31	37	2009	Wildfire	High	Unburned/Low	High	RAVG				RAVG mapped wildfire.
10	32	2	2009	Wildfire	High	Low	High	RAVG				RAVG mapped wildfire.
11	33	1	2009	Wildfire	High	Medium	High	RAVG				RAVG mapped wildfire.
12	413	1	2009	Development	High	High	High	Refresh Events	MIICA	dNBR		MIICA identified disturbance within Development Refresh Event perimeter. Severity determined by dNBR standard deviation breakpoints.
13	421	2834	2009	Clearcut	High	Low	High	Refresh Events	MIICA	dNBR		MIICA identified disturbance within Clearcut Refresh Event perimeter. Severity determined by dNBR standard deviation breakpoints.
14	422	424	2009	Clearcut	High	Medium	High	Refresh Events	MIICA	dNBR		MIICA identified disturbance within Clearcut Refresh Event perimeter. Severity determined by dNBR standard deviation breakpoints.
15	423	1749	2009	Clearcut	High	High	High	Refresh Events	MIICA	dNBR		MIICA identified disturbance within Clearcut Refresh Event perimeter. Severity determined by dNBR standard deviation breakpoints.
16	431	6951	2009	Harvest	High	Low	High	Refresh Events	MIICA	dNBR		MIICA identified disturbance within Harvest Refresh Event perimeter. Severity determined by dNBR standard deviation breakpoints.
17	432	1118	2009	Harvest	High	Medium	High	Refresh Events	MIICA	dNBR		MIICA identified disturbance within Harvest Refresh Event perimeter. Severity determined by dNBR standard deviation breakpoints.
18	433	1793	2009	Harvest	High	High	High	Refresh Events	MIICA	dNBR		MIICA identified disturbance within Harvest Refresh Event perimeter. Severity determined by dNBR standard deviation breakpoints.
19	441	19638	2009	Thinning	High	Low	High	Refresh Events	MIICA	dNBR		MIICA identified disturbance within Thinning Refresh Event perimeter. Severity determined by dNBR standard deviation breakpoints.
20	442	1535	2009	Thinning	High	Medium	High	Refresh Events	MIICA	dNBR		MIICA identified disturbance within Thinning Refresh Event perimeter. Severity determined by dNBR standard deviation breakpoints.

1 (0 out of 101 Selected)

Composite Disturbance Value Attribute Table

Rowid	VALUE *	COUNT	D_TYPE	D_SEVERITY	D_TIME	R	G	B	RED	GREEN	BLUE
0	0	2877793	No Disturbance	NA	NA	0	0	0	0	0	0
1	111	483654	Fire	Low	One Year	25	0	0	1	0	0
2	112	290323	Fire	Low	Two to Five Years	25	0	0	1	0	0
3	113	352163	Fire	Low	Six to Ten Years	25	0	0	1	0	0
4	121	186765	Fire	Moderate	One Year	25	0	0	1	0	0
5	122	105493	Fire	Moderate	Two to Five Years	25	0	0	1	0	0
6	123	121960	Fire	Moderate	Six to Ten Years	25	0	0	1	0	0
7	131	51118	Fire	High	One Year	25	0	0	1	0	0
8	132	64489	Fire	High	Two to Five Years	25	0	0	1	0	0
9	133	49453	Fire	High	Six to Ten Years	25	0	0	1	0	0
10	211	14359	Mechanical Add	Low	One Year	25	10	0	1	0.4	0
11	212	31130	Mechanical Add	Low	Two to Five Years	25	10	0	1	0.4	0
12	213	38477	Mechanical Add	Low	Six to Ten Years	25	10	0	1	0.4	0
13	221	263	Mechanical Add	Moderate	One Year	25	10	0	1	0.4	0
14	222	840	Mechanical Add	Moderate	Two to Five Years	25	10	0	1	0.4	0
15	223	4543	Mechanical Add	Moderate	Six to Ten Years	25	10	0	1	0.4	0

1 (0 out of 37 Selected)

Figure 4. Yearly and composite disturbance data attribute tables. The yearly disturbance data layers are attributed with the year, type, and severity of the disturbance as well as up to four input data sources, type and severity confidence levels, and a synopsis of the data and reasoning used to determine the map unit classification. The yearly disturbance data are compiled into a composite disturbance data layer. The

disturbance year (dist_year) is classified into a time-since-disturbance category (d_time) in the composite layer.

LANDFIRE disturbance data are developed through a multistep process that incorporates Landsat satellite imagery, disturbance polygons derived from local agencies, and other ancillary data. The remainder of this section provides a general overview of the LANDFIRE disturbance mapping process (Figure 5). More detailed information is available on the LANDFIRE website and in the literature cited below.

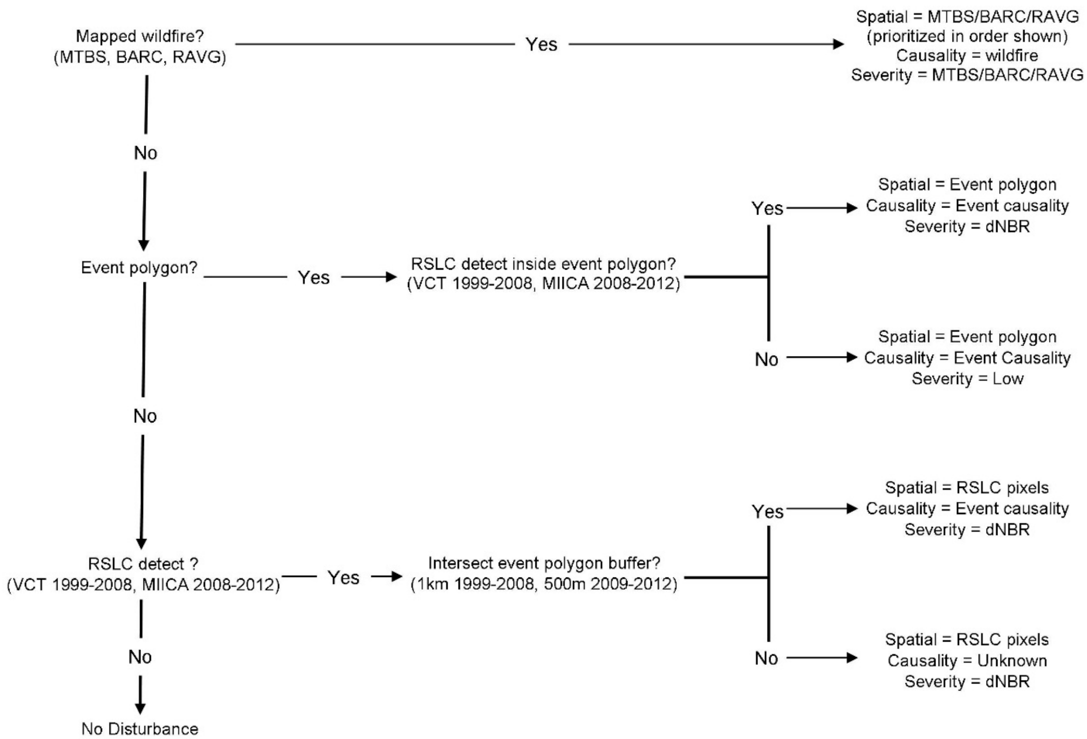


Figure 5. The LANDFIRE disturbance mapping process. LANDFIRE disturbance data are developed through a multistep process that incorporates Landsat satellite imagery, local agency derived disturbance polygons, and other ancillary data.

The first step in this process is to detect when and where disturbances have occurred. Three sources of information are used to accomplish this task: wildfire severity data from the Forest Service Remote Sensing Applications Center (RSAC), event polygons from the LANDFIRE events geodatabase, and change detection data derived from Landsat satellite imagery.

Wildfire Severity Data

RSAC manages three wildland fire severity mapping programs: Monitoring Trends in Burn Severity, Burned Area Emergency Response, and Rapid Assessment of Vegetation Condition after Wildfire. The data from these programs differ in the date of post-fire imagery and/or the severity mapping methodology used to create them. LANDFIRE uses all three datasets to map the extent and severity of wildfires.

LANDFIRE Events Data

Polygon data of vegetation and fuel management activities comprise the LANDFIRE events geodatabase. These data are obtained from federal, state, local, and private organizations and are compiled by LANDFIRE analysts. Events on national forest system lands rely heavily on data from the USDA Forest Service, Forest Activities Tracking System (FACTS). Regardless of the source, all events are crosswalked to one of 22 (including the exotic plants map unit) LANDFIRE event types (USFS 2013).

Change Detection

Lastly, LANDFIRE has incorporated two landscape change detection methodologies that apply Landsat satellite imagery in the development of the disturbance data. In the LANDFIRE 2008 mapping effort, a vegetation change and tracking process referred to as the Vegetation Change Tracker (VCT; Huang et al. 2010) was used. Beginning with the LANDFIRE 2010 mapping effort, the program adopted a new process called Multi-Index Integrated Change Analysis (MIICA; Jin et al. 2013). The MIICA process improves detection of disturbances in non-forest vegetation types, whereas VCT primarily identified disturbances in forested vegetation (D. Long, personal communication, July 23, 2013). MIICA was used to detect 2008 disturbances not identified through the VCT process, and all disturbances in 2009 through 2012. MIICA was not retroactively applied to the individual year disturbance data prior to 2008.

The second step in the disturbance mapping process is to assign causality, or disturbance type, to an identified disturbance. If the causality is know, that is, it is a mapped wildfire or LANDFIRE event, the causality is recorded in the yearly disturbance data attribute table. If the disturbance is identified through the change detection process, two additional sources of information are used to assign the likely causality: the National Gap Analysis Program's Protected Area Database and the USDA Forest Service, Pacific Northwest Research Station's SmartFire information system. Yearly disturbance layers are attributed with up to 19 of the 22 LANDFIRE event types plus an "unknown" class. This class indicates a disturbance occurred but the causality is uncertain (Table 4).

Table 4: Comparison of disturbance type attributes between LANDFIRE individual year and composite disturbance data layers. The composite vegetation disturbance (VDist) information is used to inform updates to the existing vegetation type data layer. The composite fuel disturbance (FDist) information is a subset of the VDist used to inform updates to fuel data layers.

LANDFIRE Event Type	Yearly Disturbance	VDist	Description	FDist	Applicable FDist Lifeforms
Wildfire	Wildfire	Fire	A catch-all term used to describe any non-structure fire that occurs in the wildland.	Fire	Herbaceous, Shrub, Tree
Wildland Fire Use	Wildland Fire Use				
Prescribed Fire	Prescribed Fire				
Wildland Fire	Wildland Fire				
Mastication	Mastication	Mechanical Add	A mechanical activity by which fuel is added to the natural fuelbed or in which the natural fuel structure is changed from a vertical to horizontal arrangement (e.g., mastication).	Mechanical Add	Shrub, Tree
Other Mechanical	Other Mechanical				
Clearcut	Clearcut	Mechanical Remove	A mechanical activity in which fuel is not added to the natural fuelbed (e.g., whole-tree harvesting) or in which natural fuels are removed.	Mechanical Remove	Shrub, Tree
Harvest	Harvest				
Thinning	Thinning				
Weather	Weather	Windthrow	Weather related event that results in loss of vegetation such as blowdown, hurricane, or tornado.	Windthrow	Tree
Insects	Insects	Insects-Disease	Infestations of insects and/or disease that can affect vegetative health and structure.	Insects-Disease	Shrub, Tree
Disease	Disease				
Insects/Disease	Insects/Disease				
Insecticide	Insecticide	Chemical	Application of a chemical substance such as herbicide.	NA	NA
Herbicide	Herbicide				

LANDFIRE Event Type	Yearly Disturbance	VDist	Description	FDist	Applicable FDist Lifeforms
Chemical	Chemical				
Biological	Biological	Biological	The use of living organisms, such as predators, parasites, and pathogens, to control weeds, pest insects, or diseases.	NA	NA
Development	Development	Development	Conversion of natural lands into housing, commercial, or industrial building sites. Involves permanent land clearing.	NA	NA
Exotic Plants	Exotics	Exotics	The presence of non-native species.	Exotics	Herbaceous, shrub
Planting	NA	NA	NA	NA	NA
Reforestation	NA	NA	NA	NA	NA
Seeding	NA	NA	NA	NA	NA
NA	Unknown	NA	Sources indicate that a disturbance occurred but causality is uncertain.	NA	NA

The final step in the disturbance mapping process is to map the disturbance severity. Information for determining disturbance severity may come from any one of the three data sources described above: RSAC wildfire severity, LANDFIRE events geodatabase, or remotely sensed change detection methods. Disturbance severity is assigned to one of three classes: low, moderate, or high (Table 5).

Table 5: LANDFIRE disturbance severity classes.

Severity	Description
Low	Less than 25% above-ground biomass removed.
Moderate	25 – 75% above-ground biomass removed.
High	Greater than 75% above-ground biomass removed.

The flow chart shown in Figure 5 may be used as an aid to understand this process. Where a wildfire has been mapped by one or more of the RSAC wildfire severity mapping programs, the information is used to determine the extent, year, causality (i.e., wildfire), and severity of the fire. In areas where a wildfire has not been mapped by one of the RSAC programs, but a LANDFIRE event has been mapped using other methods, the extent and causality of the event polygon are used. If the change detection process also detected the disturbance, severity is derived from the remote sensing data using the differenced Normalized Burn Ratio methodology (Key and Benson 2005). If no disturbance was detected via change detection, the year attributed to the event polygon is used and severity is set to low. Finally, if neither a wildfire or event is mapped to an area but a change is detected via remote sensing, the extent, year, and severity are determined by inference. This is done through analysis of the change detection data and assignment of causality based on proximity to event polygons and other ancillary data such as the National Gap Analysis Program's Protected Area Database and buffered SmartFire points. In addition to year, type, and severity, the yearly disturbance data layers are attributed with input data sources, type and severity confidence levels, and a synopsis of the data and reasoning used to determine the map unit classification (Figure 4).

The yearly disturbance data layers are then integrated into two composite data layers representing disturbances occurring over the previous ten year time period. In instances where multiple disturbances from different years overlap, the type and severity of the most recent disturbance is used in the composite data layer. An exception to this rule is in the case of a fire disturbance type (prescribed or wildfire) which overrides other disturbance types and is assigned to the composite layers regardless of when the fire occurred in the series of events. The disturbance type attribute of the yearly disturbance layers is reclassified into one of nine disturbance type map units in the final composite *vegetation* disturbance layer (Table 4). The year of the disturbance is classified into one of three time-since-disturbance classes: one year, two to five years, or six to ten years.

The composite *vegetation* disturbance layer is used to inform updates to the existing vegetation type, cover, and height data layers (Chapter 4). Both the yearly disturbance and composite vegetation disturbance layers are compiled from "raw" disturbance data. As such, direct comparison with existing vegetation data may reveal illogical combinations (e.g., fire and water mapped to the same pixel). When vegetation transition rules are applied to update the vegetation data layers, illogical combinations are filtered out.

The composite *fuel* disturbance layer is used to inform updates to fuel data layers (Chapter 5). The composite *fuel* disturbance layer is a subset of the composite *vegetation* disturbance layer and does not include chemical, biological, or development map units (see comparison in Table 4). The reasoning for this is that the composite fuel disturbance data layer is only applied in cases where both the post-disturbance vegetation characteristics *and* the disturbance that created those characteristics influence the post-disturbance fuels. For example, an herbicide application may cause a transition in vegetation type, cover, and/or height; and a fire behavior fuel model would be assigned based on these post-disturbance vegetation characteristics. The fact that the change was caused by the application of an herbicide does not factor into the assignment of the fuel model. This is in contrast to what would occur in a forested vegetation type after a wildfire, for example, where the post-disturbance vegetation characteristics *and* the fact that fire consumed dead wood and surface organic matter would both need to be taken into consideration in assigning the post-disturbance fuel model (Chapter 5). The composite fuel disturbance layer undergoes additional filtering to remove inconsistent disturbance/lifeform combinations (e.g., windthrow in herbaceous- or shrub-dominated landscapes, Table 4).

Considerations

Time-Since-Disturbance

LANDFIRE periodically updates the geospatial data products it develops to represent change due to disturbances; however, the update process itself takes two to three years to complete. Under the current update schedule, LANDFIRE data are typically 3–5 years out of date for any given year. In regards to the vegetation and fuel disturbance data layers, the time-since-disturbance attribute may therefore be out of date. For example, LANDFIRE 2012 data reflects conditions through the end of 2012. Thus, a disturbance that occurred in 2012 would be assigned to the one year time-since-disturbance class in the LANDFIRE 2012 data. However, the LANDFIRE 2012 data were released in the later months of 2014. For application in 2015, the original 2012 disturbance is 3 years old putting it in the 2–5 year time-since-disturbance class (Table 6). Likewise, disturbances that occurred in 2008 and 2009 should be shifted from the 2–5 year time-since-disturbance class to the 6–10 year class in 2014.

Table 6: Comparison of time-since-disturbance (TSD) between currency and release dates. For application in 2015, LANDFIRE 2012 disturbance data in the one year TSD class should be updated to the two to five year class. Likewise, disturbances that occurred in 2008 and 2009 should be updated to the six to 10 year TSD class.

Disturbance Year:	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Data TSD (Years)	10	9	8	7	6	5	4	3	2	1	--	--
Current (TSD) Years	12	11	10	9	8	7	6	5	4	3	2	1

Whether this is of concern or not depends on the particular data products, their intended use, and the location of your assessment. For example, the assignment of fire behavior fuel model for use in fire behavior simulation is sensitive to the time-since-disturbance attribute. This is especially true in areas of the country where vegetation growth and fuel accumulation are rapid.

Disturbance Type

Disturbance type, or causality, is assigned to the vegetation disturbance and fuel disturbance data layers by pairing remote sensing data with information from the LANDFIRE Events Geodatabase. Individual disturbances are first classified into one of 22 LANDFIRE event types. Nineteen of these event types, plus an “unknown” class, are used to attribute the yearly disturbance data layers. The event types of the yearly layers are then reclassified into one of nine disturbance types in the composite vegetation disturbance layer and six types in the composite fuel disturbance layer (Table 4). Two disturbance types in particular—mechanical add and mechanical remove—can be especially challenging to assign from the information available in the events data but are very important for determining post-disturbance fuel. Whether the surface fuels (e.g., branches, needles, bark) generated from a forest management activity are added, rearranged, or removed from a site is highly dependent on factors such as site characteristics, management techniques, and management objectives. The management techniques and objectives are strongly influenced by law, regulations, and policies (local through national). These factors are highly variable in both location and time. For example, in more humid areas of the United States where downed wood decomposes quickly, activity fuel may be left on site to decompose and provide valuable nutrients to the soil. Conversely, in drier climates where this fuel takes years to decades to decompose, local, regional and/or national regulations or policy may dictate that activity fuel be removed from the site.

The information in the events data is typically not specific enough to discern these differences and LANDFIRE updates must therefore resort to the broad definitions of mechanical add/remove shown in Table 4. For local applications however, local resource professionals often have the institutional knowledge and/or ancillary information to critically critique, and update if necessary, disturbance type attributes.

Most Recent Disturbance Rule

As discussed above, in instances where multiple disturbances from different years overlap, the composite disturbance data layer is assigned the attributes of the most recent disturbance. The only exception to this rule is if fire is one of the disturbances, in which case the severity and time-since-disturbance of the fire is assigned to the composite layer regardless of when it occurred in the series of events. Multiple entries in the same treatment unit are quite common (e.g., a thinning treatment followed by treatment of activity fuels). In areas where timber harvesting is common, four or more entries may be found in short succession (e.g., a pre-treatment, one or more harvest entries, a fuel treatment, and site-preparation for planting or natural regeneration). A harvest treatment is also common, as timber salvage, after a fire.

In these situations the “most recent disturbance” rule, or “fire overrides other disturbances” rule, can lead to issues of content accuracy in the composite disturbance layers. For example, consider a high-severity harvest, such as a clearcut or shelterwood cut, followed by a low-severity disturbance, such as site-preparation or piling activity fuels. If these subsequent activities are at least a year apart, the composite data layer will be assigned “low-severity,” even though all or most of the overstory vegetation was removed.

New Disturbances

The above considerations about time-since-disturbance and disturbance type attributes were presented in the context of critiquing disturbances that were already mapped and included in the LANDFIRE disturbance data products. As discussed previously, the composite disturbance data may be 3–5 years out of date upon time of version release. Updates are therefore often necessary, especially in actively managed landscapes or landscapes in which natural disturbances have occurred after the currency date of the latest LANDFIRE version. New disturbances may be added to the vegetation and fuel disturbance data layers using a variety of geospatial techniques and tools. The most appropriate technique may be influenced by the availability of recent disturbance data, the thematic and spatial detail of the data, and the experience of the analyst. For example, recent disturbance data may be in the form of a polygon shapefile depicting the location, extent, and type of disturbance without information on severity (e.g., locally developed prescribed fire burn unit map), or in the form of a raster data layer representing multiple classes of severity (Figure 6 e.g., RSAC wildfire severity data). Regardless of the techniques applied, new disturbances must be attributed with type, severity, and time-since-disturbance to be added to the vegetation disturbance and fuel disturbance data layers.

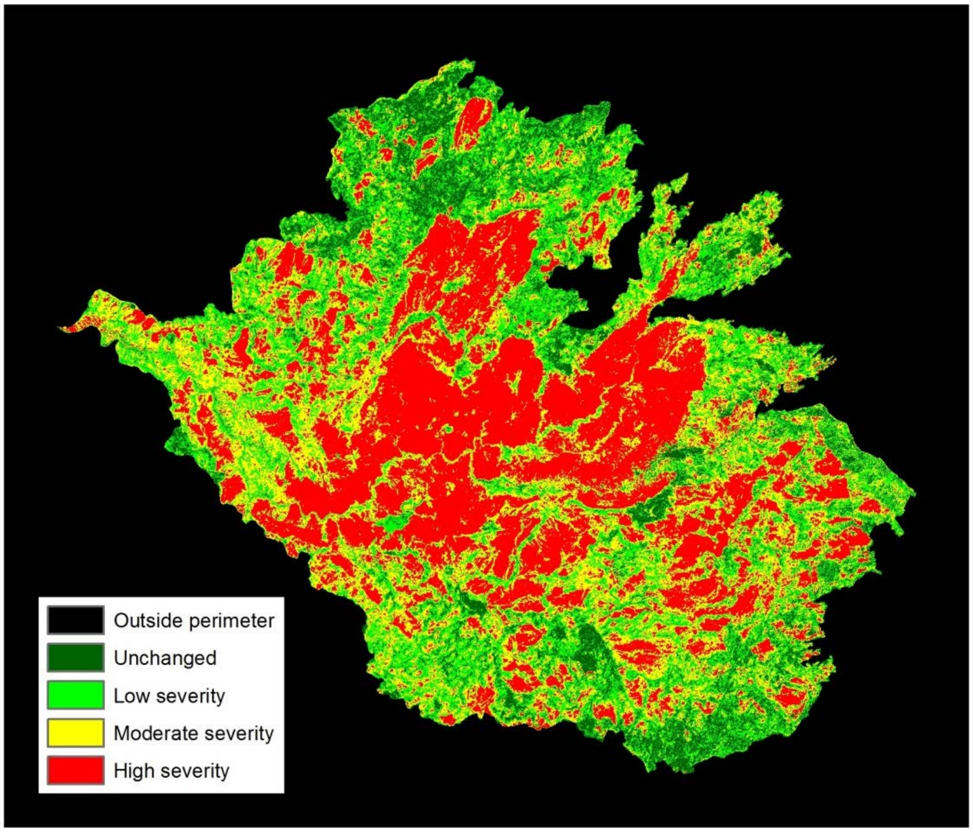


Figure 6. Four class severity classification of the 2013 Rim fire in California. Data were acquired from the U.S. Forest Service Remote Sensing Applications Center, Rapid Assessment of Vegetation Condition after Wildfire program.

Chapter 4: Vegetation

LANDFIRE develops geospatial data of potential and existing vegetation. The potential vegetation products include environmental site potential and biophysical setting. In contrast to the environmental site potential, the biophysical setting reflects potential for the historically dominant vegetation. The existing vegetation products include existing vegetation type, existing vegetation cover, existing vegetation height, and succession class. These six vegetation products are foundational to the development of other LANDFIRE geospatial data depicting fuel and fire regime characteristics.

This chapter presents an overview of the LANDFIRE vegetation mapping process, common considerations for critiquing LANDFIRE vegetation data, and examples of common pitfalls.

Vegetation Mapping Process

Potential Vegetation

Potential vegetation refers to the vegetation that could be supported at a given site based on the site's biophysical environment. LANDFIRE maps two representations of potential vegetation: environmental site potential and biophysical setting. Environmental site potential represents the late successional vegetation community that may become established at a site in the absence of disturbance. Biophysical setting represents the vegetation community that may have been dominant at a site prior to Euro-American settlement based on both the biophysical environment and an approximation of the historical disturbance regime.

Potential vegetation is mapped by LANDFIRE using a predictive modeling approach referred to generally, as *classification and regression tree* (CART; Figure 7) analysis, in conjunction with rule-based mapping techniques. First, field plot data (available in the LANDFIRE Reference Database; LFRDB [n.d.]), are keyed to environmental site potential classes based on the presence and abundance of indicator plant species that identify the biophysical conditions of the site. These plots are then intersected and attributed with information from biophysical gradient data layers (e.g., soil depth, average temperature, and average daily precipitation). The gradient layers are modeled from climate, soil, and topographic data and indirect topographic gradients such as elevation, slope, and indices of slope position. The information gathered from plot locations is then used as training data to develop the CART model—a statistical model used to predict a dependent variable (environmental site potential class) based on correlation with the independent variables (biophysical gradients). The CART model is then applied spatially to create a draft map of the environmental site potential of every pixel across the landscape based on combinations of the biophysical gradient data. The draft product is then refined using rule sets derived from the Nature Serve

Ecological Systems map unit descriptions and expert review.

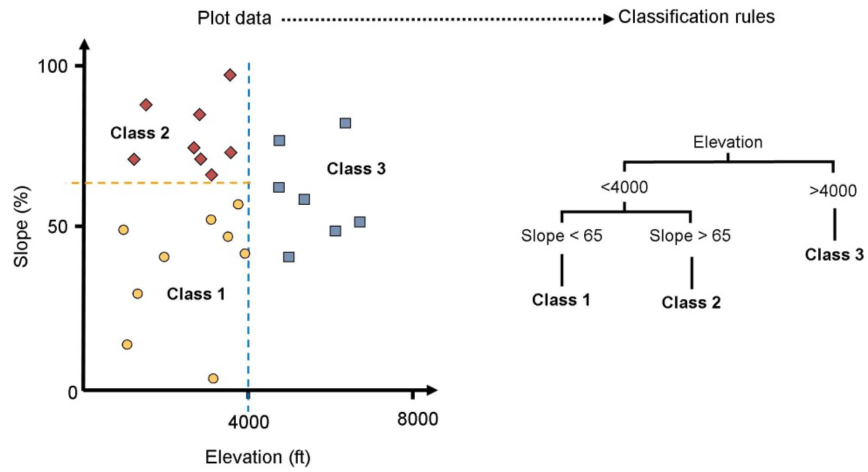


Figure 7. Classification tree conceptual diagram. In this simplified example, three classes of vegetation are plotted in respect to two biophysical gradients: elevation and slope (left side of figure). The relationship between the three vegetation classes and two biophysical gradients are then translated into classification rules (right side of figure), which are then in turn used to build spatial data layers. Approximately 40 biophysical gradients are used in the creation of the LANDFIRE potential vegetation data layers**.**

The environmental site potential data layer becomes the starting point for mapping Biophysical Settings. Environmental site potential units are associated with biophysical setting units using rule sets based on assumptions pertaining to vegetation dynamics and disturbance regimes. For example, an environmental site potential that is dominated by shade-tolerant species such as Douglas-fir or grand fir in the absence of disturbance may be mapped as a ponderosa pine- or western larch-dominated biophysical setting in an area with a frequent low-severity fire regime that would favor species that are less shade-tolerant and more fire-adapted. In other cases, alternate CART models were built to map biophysical settings from General Land Office survey data and Natural Resource Conservation Service Ecological Site Descriptions.

Existing Vegetation

Existing vegetation refers to the vegetation that is currently present on a given site. LANDFIRE maps four characteristics of existing vegetation: type, cover, height, and succession class. Existing vegetation is mapped using a predictive modeling approach similar to that used for potential vegetation; the primary difference is the input data. Like potential vegetation, methods for mapping existing vegetation type apply geospatial data of biophysical gradients and information from field plots. Because plot data can sometimes be many years old and vegetation characteristics may change rapidly, an additional filtering process is applied to ensure that current data are being used to develop the CART models. The existing vegetation type mapping process also includes data derived from Landsat satellite imagery as input. The base Landsat imagery used by LANDFIRE to derive existing vegetation products was acquired in the years 1999–2003, with newer imagery brought in to detect changes over time due to disturbance during the disturbance update process (Chapter 3).

Existing vegetation cover represents the area of the ground covered by a vertical projection of the canopy: in other words, the area of the ground covered if one were to look straight down from above (Figure 8). This is not to be confused with canopy closure, which is the proportion of the sky hemisphere obscured by vegetation when viewed from a single point (Jennings et al. 1999). Cover is mapped separately for herbaceous, shrub, and tree lifeforms using a predictive modeling approach based on plot data, satellite imagery, and biophysical gradient data layers. The canopy cover of each lifeform is binned into ten-percent classes[1] and then merged into a composite data layer in which the upper-layer lifeform's cover is assigned to the pixel. The training data for each lifeform are based on plot-level, ground assessments. However for the tree lifeform, plot canopy cover is modeled using a stem-mapping approach developed by Toney et al. (2009). This method was applied to the LANDFIRE 2001 data and is being applied to subsequent versions as an improvement over the canopy cover mapping in LANDFIRE National, which tended to over-predict tree canopy cover (Nelson et al. 2013, USFS [n.d.], Forest Canopy Cover…).

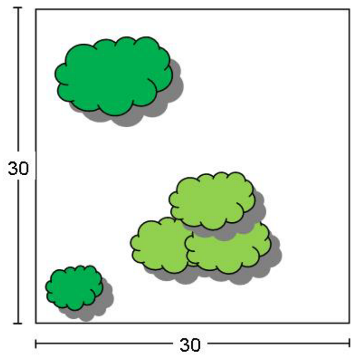


Figure 8. Vertically projected canopy cover. Existing vegetation cover represents the vertically projected canopy cover of the dominant lifeform for a pixel. In this example, the canopy cover within a 30-by-30 meter pixel is approximately 25%.

The existing vegetation height product represents the average height of the dominant lifeform. Like canopy cover, canopy height is mapped separately for herbaceous, shrub, and tree lifeforms using plot data, satellite imagery, and biophysical gradient data layers in a predictive modeling approach. The height of each lifeform is binned into classes and then merged into a composite data layer in which the upper-layer lifeform's height is assigned to the pixel (Table 7). For forests, a Shuttle Radar Topography Mission (SRTM) derived vegetation height product (Kellendorfer et al. 2004) is added to the other data sources for predictive modeling in LANDFIRE 2001 (Toney et al. 2012). The addition of the SRTM data provides a vertical structure measurement unavailable from the two-dimensional Landsat imagery which improved forest height mapping (Nelson et al. 2013, LANDFIRE 2008). Existing vegetation height for forests represents the average height of the dominant and co-dominant trees (weighted by basal area) for the pixel (Toney et al. 2012). In other words, the height value does not represent the average height of all individual trees, nor does it represent the average height of only the dominant trees. For non-forest areas, existing vegetation height represents the average height of the dominant lifeform. This is determined from species height weighted by species cover composition.

[1] For Alaska, tree and shrub cover is binned into three classes: 10%-25%, 26%-60%, and > 60%; herbaceous cover is binned into two classes: 10%-60% and > 60%.

Table 7: LANDFIRE height classes by lifeform and geographic area.

Lifeform:	Height Class (m) CONUS and HI	Height Class (m) Alaska
Herbaceous	0 - 0.5	0 - 0.5
	0.5 - 1	> 0.5
	> 1	
Shrub	0 - 0.5	0 - 0.5
	0.5 - 1	0.5 – 1.5
	1 – 3	> 1.5
	> 3	
Tree	0 - 5	No difference
	5 - 10	
	10 - 25	
	25 - 50	
	> 50	

The final characteristic of existing vegetation mapped by LANDFIRE is succession class. Succession class represents the current stage of vegetation development within an individual biophysical setting. It is very important to understand that the succession class should not be used independent of its biophysical setting. **Without its biophysical setting the succession class has no definition**. LANDFIRE maps up to seven succession classes using a rule-based approach—for each biophysical setting, a succession class is assigned based on rules that define specific combinations of existing vegetation type (primarily lifeform), existing canopy cover, and existing canopy height (Figure 9). Up to five of the seven succession classes are used to represent development stages characteristic of those found under the historical disturbance regime. Two classes are used to represent uncharacteristic conditions. Uncharacteristic native identifies native vegetation conditions that would be unlikely to occur under the historical disturbance regime, such as excessive canopy cover for a biophysical setting succession class with a frequent low-severity fire regime. Uncharacteristic exotic identifies areas in which exotic species have partially or completely replaced the native species.

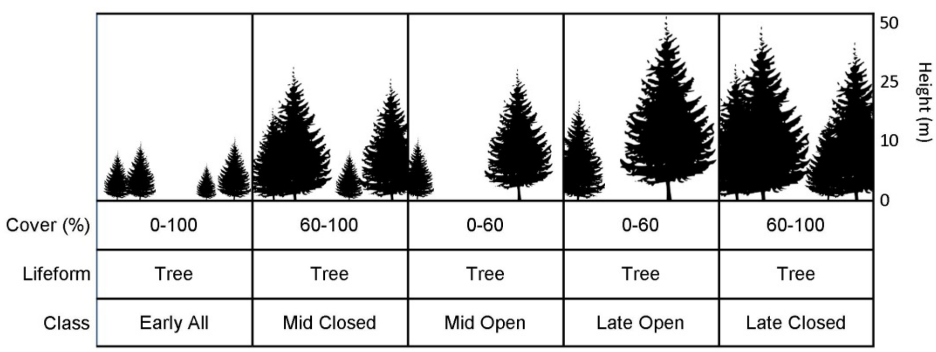


Figure 9. Typical five-class model for a forested biophysical setting, demonstrating succession class assignment based on vegetation characteristics. LANDFIRE maps up to seven succession classes using a rule-based approach—for each biophysical setting, a succession class is assigned based on rules that define specific combinations of existing vegetation type (primarily lifeform), existing canopy cover, and existing canopy height.

Updating Existing Vegetation

The existing vegetation products are periodically updated for changes due to disturbances and growth. The disturbance updating process was discussed in Chapter 3. Changes due to growth are incorporated in the mapping process after the disturbance update through a series of transition rules. Rules for updating the non-forest vegetation type for growth are developed based on the vegetation dynamics development models and the judgment of LANDFIRE analysts and other regional experts. Transition rules for forest vegetation type, cover, and height were developed based on forest growth simulations for Forest Inventory and Analysis plots modeled in the Forest Vegetation Simulator (FVS, Dixon 2002; Nelson et al. 2013). In Hawaii and Alaska (except southeast AK), where Forest Inventory and Analysis data are not available, forest transitions were developed by LANDFIRE analysts and other regional experts (Nelson et al. 2013). In LANDFIRE 2008 and 2010 the vegetation products were updated for both disturbances and growth. In LANDFIRE 2012, the vegetation products were updated for disturbance only. The transition rules are documented in databases available from the LANDFIRE Program website.

Considerations

One Classification, Three Interpretations

LANDFIRE uses the same map unit classification and naming system for the environmental site potential, biophysical setting, and existing vegetation type data layers. However, each of these layers must be interpreted differently, since they have different definitions and processing methods. A first step in identifying and mitigating possible vegetation type mapping issues (existing or potential) is to have a thorough understanding of this map unit classification and naming system and how it is used in the LANDFIRE existing vegetation type, environmental site potential, and biophysical setting data layers.

LANDFIRE uses NatureServe's Ecological Systems classification (Comer et al. 2003) as the primary map units and naming system for its existing vegetation type, environmental site potential, and biophysical setting products. The Ecological Systems classification units are intended to represent *existing* vegetation communities that persist for anywhere from 50 to hundreds of years, but LANDFIRE applies this concept in three different ways. In the existing vegetation type data layer, Ecological Systems are used as they were designed—to classify existing vegetation communities. For the environmental site potential data layer, LANDFIRE uses Ecological Systems to classify potential vegetation communities that could exist on a site given its biophysical characteristics in the absence of disturbance. Environmental site potential classes are modified to map LANDFIRE's biophysical setting concept which represents vegetation communities that may have been present prior to European-American settlement based on the biophysical environment and the historical disturbance regime. These are major differences and can have substantial effects on interpreting the data. For example, the same pixel classified as a Douglas-fir/grand fir forest environmental site potential based on the physical environment could be classified as a ponderosa pine forest biophysical setting, because of its historical fire regime, and a grass- or shrub-existing vegetation type due to a recent high-severity fire event. In rangeland, the same pixel classified as pinyon-juniper environmental site potential could be classified as a grassland biophysical setting, because of its historical fire regime, and a shrub existing vegetation type due to reduction in fire frequency.

Another important consideration specific to LANDFIRE existing vegetation type is that the NatureServe Ecological Systems map units represent vegetation communities that are typically comprised of groups of species. Most existing vegetation map users are more familiar with the concept of cover types. Cover types, in contrast to Nature Serve Ecological Systems map units, represent one or more dominant species at a single point in time. NatureServe Ecological Systems map units are not equivalent to cover types. The LANDFIRE existing vegetation type attribute table provides a crosswalk to the Society of American Foresters (SAF) and Society for Range Management (SRM) cover types classes as a guide to help users better understand LANDFIRE’s map units. However, because SAF and SRM map units represent cover types and LANDFIRE’s units represent systems, the crosswalk should not be interpreted as an exact match.

Potential vs. Existing Vegetation Type Rectification

The LANDFIRE potential vegetation data layers (environmental site potential and biophysical setting) were mapped using a predictive modeling approach based on plot data and biophysical gradient data layers, but did not incorporate imagery or use the existing vegetation type to modify the mapping process. This results in the potential vegetation data layers being inherently coarser in concept than the existing vegetation type data layer, which integrates Landsat satellite imagery. However, due to time and budgetary constraints, the LANDFIRE program has not been able to rectify either environmental site potential or biophysical setting with existing vegetation as to the inclusion or exclusion of specific existing vegetation types that would better depict site potential, thus improving content accuracy. Therefore, the user may find illogical combinations of these data layers and existing vegetation type for the same pixel, such as an existing vegetation type mapped to the same pixels as a biophysical setting that would not support the vegetation type due to moisture or topo-edaphic (i.e., soil) constraints. An example of this would be a riparian existing vegetation type, such as upper montane riparian, mapped to a non-riparian biophysical setting, such as sagebrush steppe. In the vegetation departure data products (Chapter 6) this situation may falsely indicate ecological departure. In these situations it can be difficult to determine which data layer is correct, but it is typically assumed that the existing vegetation type data layer is more likely to accurately depict the site because it integrates satellite imagery, and plot data go through additional filtering in its development.

Map Zone Boundaries

Because LANDFIRE vegetation data were mapped independently by map zone (Figure 2), differences or abrupt changes are sometimes found along map zone boundaries. For example, where map zone boundaries coincide with ecological division boundaries (Comer et al. 2003), there may be a change in the existing vegetation type map unit for similar vegetation types, such as Colorado Plateau pinyon-juniper woodland (Intermountain Basins ecological division) to Southern Rocky Mountain pinyon-juniper woodland (Rocky Mountain ecological division) (Figure 10). This does not necessarily indicate a mapping issue; however, secondary data products for which existing vegetation type is a variable in their mapping methodology—such as succession class (below), fire behavior fuel model (Chapter 5), and the fire regime and vegetation departure products (Chapter 6)—may be influenced by the difference in vegetation type map unit.

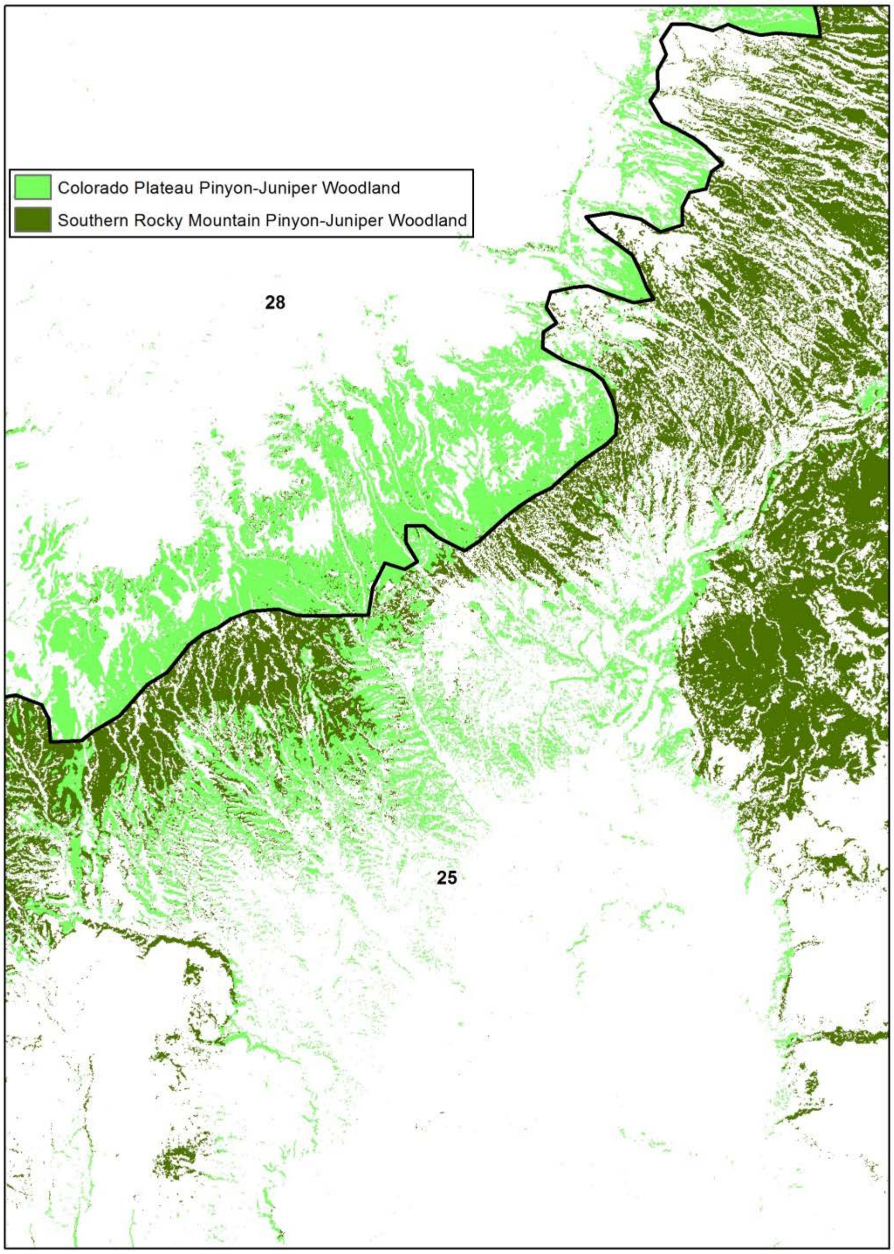


Figure 10. Comparison between the Colorado Plateau pinyon-juniper woodland existing vegetation type (Intermountain Basins ecological division) and the Southern Rocky Mountain pinyon-juniper woodland existing vegetation type (Rocky Mountain ecological division) at the map zone 25 and 28 map zone boundary. Secondary data products for which existing vegetation type is a variable in their mapping methodology may be influenced by the difference in vegetation map units at the boundary.

Existing vegetation cover is a primary variable in mapping secondary data products (i.e., succession class, fire behavior fuel model, and vegetation departure products). An abrupt change in vegetation cover within the same existing vegetation type is sometimes found at map zone boundaries (Figure 11). This may occur if the satellite imagery used for the adjacent zones was collected in different years and those years received significantly different amounts of precipitation, especially in dry southwestern ecosystems, or if different configurations of plot data were used between the zones (D. Long, personal communication, July 6, 2015). This may lead to an artificial demarcation in secondary data products and subsequently the results of analyses that use these products such as fire behavior and vegetation departure.

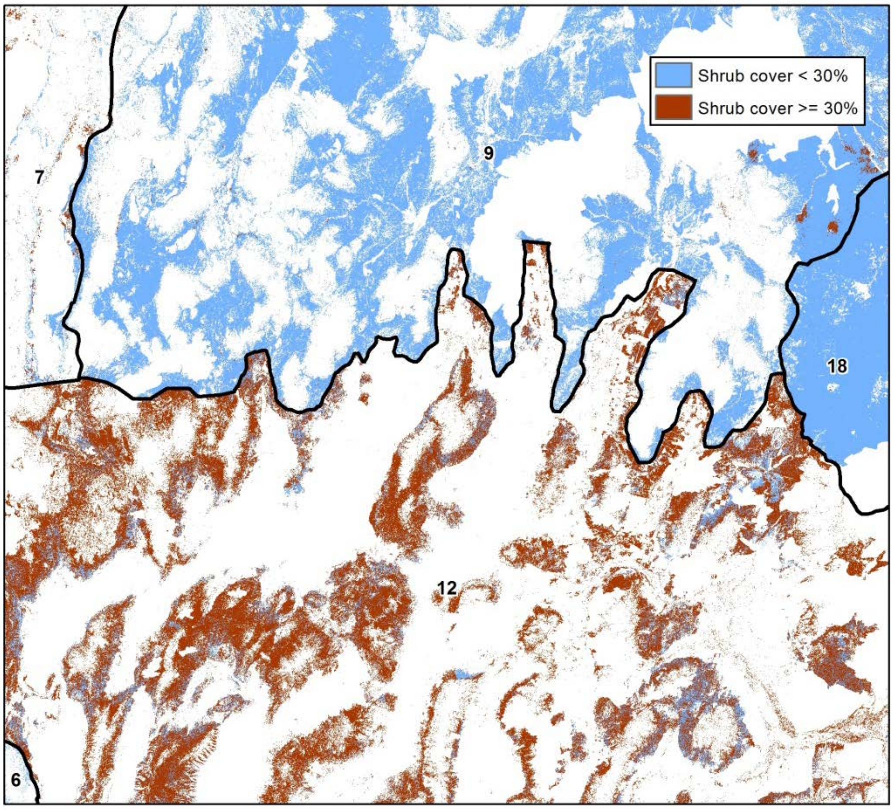


Figure 11. Abrupt change in canopy cover in the Inter-Mountain Basins Big Sagebrush Shrubland existing vegetation type at the boundary between map zones 9 and 12. This can have a profound effect on secondary data layers that use existing canopy cover as a mapping variable.

Succession Class Mapping Rules

LANDFIRE succession class is mapped using a rules-based approach. The mapping rules are based on unique combinations of biophysical setting and existing vegetation type, existing vegetation cover, and existing vegetation height. The rules were developed through a series of workshops by regional experts in vegetation dynamics and fire ecology (Rollins 2009) and are described in both the LANDFIRE vegetation dynamics model descriptions and vegetation dynamics model tracker database available for download from the LANDFIRE website.

One primary consideration in critiquing succession class mapping rules is that the modelers who developed the vegetation dynamics models sometimes emphasized species composition and structure in the definition of classes, while the mappers relied primarily on lifeform and structure to map the classes. As a result, in cases where species composition differentiates between classes of the same structure (Figure 12), LANDFIRE may not have mapped the succession classes appropriately. Post-processing in a GIS may be required to refine the succession class map based on species composition.

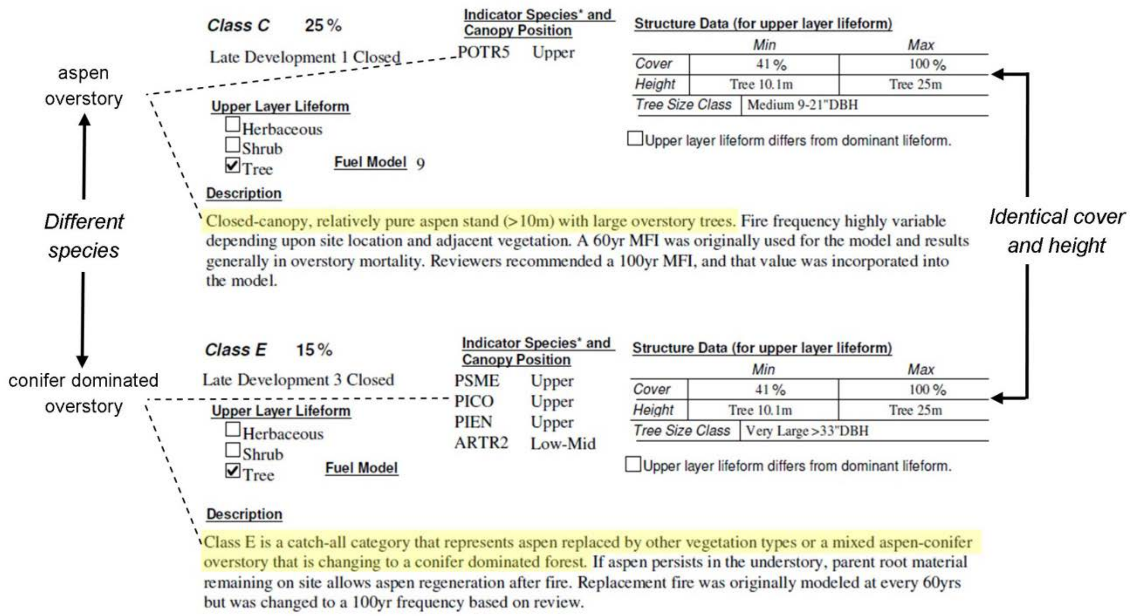


Figure 12. Example of a biophysical setting where species composition (not lifeform) is the primary variable for differentiating between succession classes. As of version 1.2.0 (LANDFIRE 2010) succession class E was not mapped for this biophysical setting in map zone 21 thus requiring GIS post-processing to map it.

Another consideration is that structure, as defined in the vegetation dynamics models, may be difficult to map using remote-sensing based techniques (as is done in mapping LANDFIRE existing vegetation). For example, although a rule may differentiate between succession classes based on whether herbaceous vegetation height is less than or greater than 0.5m, this level of precision is difficult to map accurately using the satellite-based predictive modeling approach described above (Riano et al. 2002). Conversely, the existing vegetation height classes in forested vegetation (Table 7) may be too coarse to accurately differentiate between succession classes (e.g., 10m to 25m and 25m to 50m) or a poor surrogate for vegetative development stage altogether. Chapter 6 contains additional considerations for using the LANDFIRE succession class data layer in vegetation departure analyses.

Chapter 5: Fuels

LANDFIRE produces geospatial data depicting surface and canopy fuel characteristics. For surface fuel data we will focus on the 40 Scott and Burgan fire behavior fuel models data layer (Scott and Burgan 2005), as it is the most commonly used LANDFIRE surface fuel data product. However, the concepts presented in the Considerations section of this chapter are applicable to the other LANDFIRE surface fuel products as well—13 Anderson fire behavior fuel models (Anderson 1982), Canadian forest fire danger rating system fuel types, fuel characteristic classification system fuelbeds, and fuel loading models.

In combination with forest canopy cover, forest canopy height, and topographic data (slope, aspect and elevation), LANDFIRE fire behavior fuel model and canopy fuel data (canopy base height and bulk density) can be used to create a “landscape” file (LCP) required by common geospatial fire behavior modeling systems used in the United States, such as FlamMap (Finney 2006), FARSITE (Finney 1998), and FSPro (USDAFS 2009). Although an LCP file may be downloaded directly from the LANDFIRE data distribution website, we do not discuss the critique or modification of these data in the LCP file format.

This chapter presents an overview of the LANDFIRE fuel mapping process and common considerations for critiquing LANDFIRE fuel data with examples relevant to local applications.

Fuel Mapping Process

Surface Fuels

Technically, a fire behavior fuel model—Anderson (1982) or Scott and Burgan (2005)—is a set of fuelbed inputs required by fire behavior modeling systems that use the Rothermel (1972) fire spread model. More practically speaking, a fire behavior fuel model represents a range of fuelbed conditions (e.g., load, depth, surface-area-to-volume ratios) in which fire behavior may be expected to respond similarly to changes in fuel moisture, slope, and wind speed (Figure 13). In this sense, a fire behavior fuel model is not so much a model of fuels as it is a model of fire behavior.

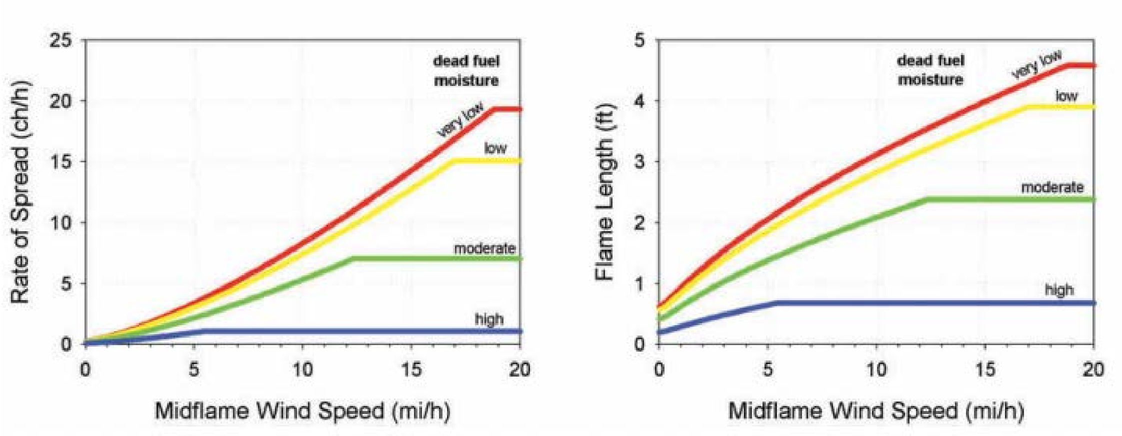


Figure 13. Differences in rate of spread and flame length by dead fuel moisture content and wind speed for fuel model Timber-Understory 1 (Low Load Dry Climate Timber-Grass-Shrub; Scott and Burgan 2005).

Like succession class (Chapter 4), all LANDFIRE surface fuel data products are mapped using an expert-opinion, rule-based approach, where mapping rules are based on unique combinations of: existing vegetation type, cover, and height; biophysical setting; and disturbance (Chapters 3 & 4). Fire behavior fuel model mapping rules were developed by fire and fuel specialists through a series of fuel calibration workshops held across the United States. The purpose of these workshops was to elicit regional expertise about fire behavior characteristics (i.e., how fire burns) in various vegetation types and structures. The calibration workshops were conducted at the extent of a LANDFIRE map zone or multiple adjacent zones. There are 80 LANDFIRE map zones across the continental U.S., Alaska, and Hawaii, ranging in size from 4 to 60 million acres (Figure 2).

The LANDFIRE total fuel change tool (formally known as ToFu Δ) (LFTFCT 2011) is a custom ArcGIS toolbar that links to the national fuel mapping rules through a Microsoft Access database (Figure 14). This tool, originally developed for use in the national calibration workshops, can now be downloaded from the Wildland Fire Management Research, Development and Application website and is highly useful in local LANDFIRE fuel data critiques.

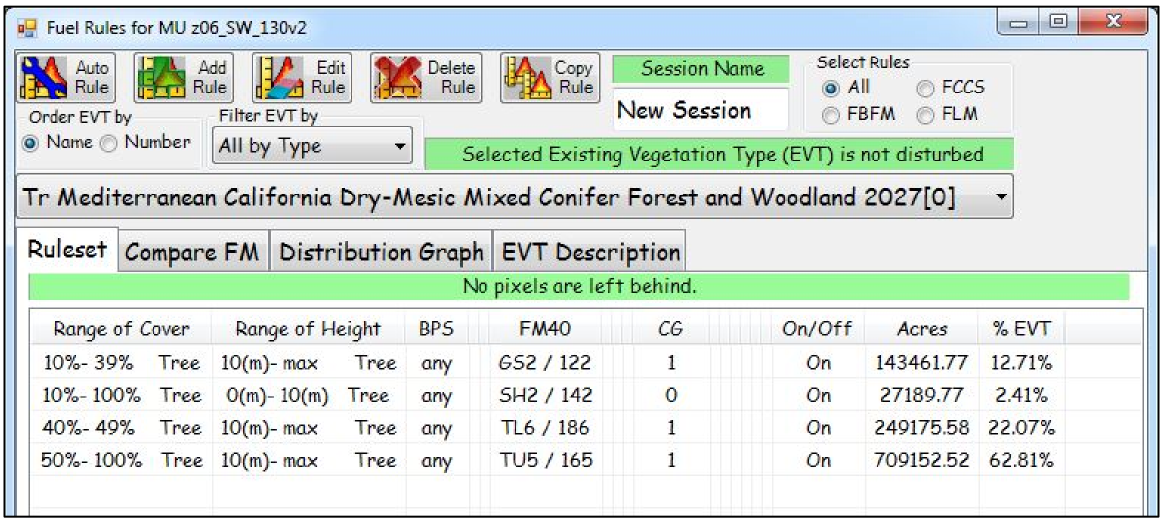


Figure 14. Example LANDFIRE Total Fuel Change Tool (LFTFCT) rule set. The LFTFCT is a custom ArcGIS toolbar that links to the LANDFIRE fuel mapping rules through a Microsoft Access database.

Canopy Fuels

The LANDFIRE canopy fuel data products include canopy base height, canopy bulk density, forest canopy cover, and forest canopy height. Forest canopy cover and canopy height values represent the midpoint of the existing vegetation cover and height data layer classes, respectively. These values are used in some fire behavior modeling systems as variables in predicting dead woody fuel moisture, wind reduction, and crown fire spotting potential. All four variables are required to model crown fire behavior using U.S. fire behavior modeling systems.

Canopy base height is defined as the lowest height above the ground at which there is sufficient available fuel (i.e., ≤ 0.25 inch diameter) to propagate fire vertically through the canopy. It is important to differentiate canopy base height—which is a property of the group of trees represented by the pixel—from *crown* base height, which is a property of an individual tree. Canopy base height is an important variable for fire behavior modeling, as it is used to predict whether crown fire initiation is possible under a given set of environmental conditions (Scott and Reinhardt 2001; Scott 2012). Prior to LANDFIRE 2012, canopy base height was mapped based on plot level averages. Various combinations of existing vegetation type, cover, and height values were crosswalked to an average canopy base height value of associated plots. For the LANDFIRE 2012 canopy base height data layer, a predictive modeling approach was implemented where field referenced plot data were used to develop regression equations based on statistical relationships between canopy base height and existing vegetation type, cover, and height (USGS 2010).

Canopy bulk density is the mass of available canopy fuel per unit canopy volume (Scott and Reinhardt 2001). Like canopy base height, canopy bulk density is a property of a group of trees—*crown* bulk density is a property of an individual tree. In fire behavior modeling, canopy bulk density is used to predict whether an active crown fire is possible under a given set of environmental conditions assuming that a crown fire has initiated (Scott and Reinhardt 2001; Scott 2012). LANDFIRE maps canopy bulk density using a predictive modeling approach based on forest canopy cover, forest canopy height, and membership to a pinyon-juniper existing vegetation type as input to a generalized linear model (Reeves et al. 2009).

In deciduous forest vegetation types—typically not considered prone to crown fire—LANDFIRE assigns canopy base height and canopy bulk density values that prevent fire behavior modeling systems from predicting crown fire. Forest canopy cover and forest canopy height values are still mapped to account for the canopy's effect on fuel moisture and wind reduction.

Fuel Updates

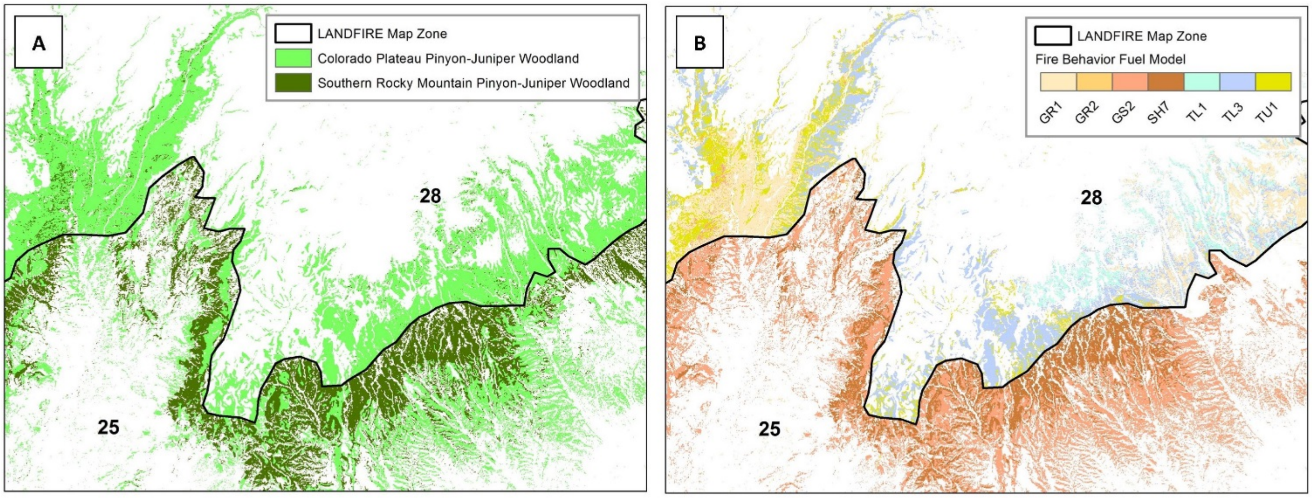
Because surface and canopy fuel mapping rules are tied to existing vegetation type, cover, and height, updates to existing vegetation data due to growth and vegetation succession automatically account for updates to fuels in non-disturbed areas. Whether an update to the fuel data layers occurs or not depends on the magnitude of the change and the threshold values in the mapping rules.

Rules for disturbed areas are independent of rules for non-disturbed areas so that the disturbance type, severity, and time-since-occurrence can be taken into account in combination with the post-disturbance vegetation characteristics, including unique lifeform and species specific disturbance response as discussed in the previous sections. The one-year time-since-disturbance category is used by LANDFIRE to update the immediate post-fire effects to canopy fuels but not used in the assignment of post-disturbance fire behavior fuel model. Fire behavior fuel model is the same for the one-year and two- to five- year time-since-disturbance categories, which are considered to represent the second growing season after the event (C. Martin, personal communication, July 10, 2015).

Considerations

Map Zone Boundaries

As mentioned earlier, fire behavior fuel model mapping rules are developed for individual map zones or groups of adjacent zones based on unique combinations of existing vegetation type, cover, and height; biophysical setting; and, disturbance. It is common to find differences in mapping rules between adjacent map zones that may lead to an "artificial edge" at the zone boundary (Figure 15). In situations where your analysis area overlaps more than one LANDFIRE map zone, a primary consideration is whether there are differences in mapping rules between the zones. If so, determine whether those differences are legitimate or if the rules from one zone more appropriately fit the analysis area as a whole. If working in an area with pinyon-juniper vegetation types, a specific mapping rule issue to watch for is whether or not there are differences between zones in the assignment of canopy fuels. In some cases, the rules for one map zone will consider the canopy fuels in pinyon-juniper vegetation types as part of the surface fuel model, while the rules for an adjacent map zone will not. This may lead to prediction of crown fire on one side of the zone boundary and surface fire on the other. The discrepancies are due to differences in mapping methodology rather than actual fire behavior potential. There may be valid reasons for each case but consistency should be strived for when an analysis area intersects multiple map zones, to ensure consistent interpretation of the results across the entire analysis area.



Existing Vegetation Type	Zone 28				Zone 25			
	Tree Cover (%)	Tree Height	FM	CG	Tree Cover (%)	Tree Height	FM	CG
Colorado Plateau Pinyon-Juniper Woodland	10-29	Any	GR1	1	10-19	Any	GR2	0
	30-39	Any	TU1	1	20-49	Any	GS2	0
	40-59	Any	TL3	1	50-100	Any	TL3	1
	60-100	Any	TL1	1	-	-	-	-
Southern Rocky Mountain Pinyon-Juniper Woodland	10-19	Any	GR2	1	10-29	Any	GS2	0
	20-59	Any	GS2	1	30-49	Any	SH7	0
	60-100	Any	TL3	1	50-100	Any	TL3	1

Figure 15. Example of variation in fire behavior fuel mapping rules by existing vegetation type and map zone. Panel A shows the existing vegetation type at the map zone boundary; panel B shows the fire behavior fuel model. FM refers to the standard Fire Behavior Fuel Model (Scott and Burgan 2005). CG refers to the canopy guide feature in the LANDFIRE Total Fuel Change Tool that controls how canopy fuels are mapped.

Multiple inconsistencies between map zones can be seen in Figure 15. The predominant pinyon-juniper existing vegetation type in map zone 28 is Colorado Plateau pinyon-juniper woodland; in map zone 25 it is southern Rocky Mountain pinyon-juniper woodland (Figure 15A). The fire behavior fuel model mapping rules for these two vegetation types vary both by type and by map zone, resulting in the obvious difference in fuel model seen at the boundary (Figure 15B). Furthermore, in map zone 28, the rules for both vegetation types include the assignment of canopy fuels (i.e., canopy guide of 1); in map zone 25 the rules do not assign canopy fuels to pixels with less than 50% canopy cover, indicating that the trees are part of the surface fuel stratum. This inconsistency forces a different interpretation of fire behavior modeling results for each map zone.

Application Scale and Location

As stated earlier, fire behavior fuel model mapping rules were developed at regional workshops for application to individual, or groups of adjacent, map zones. While these rules may be appropriate at this scale, they may need to be adjusted for application at finer scales. In other words, the “best fit” for an entire map zone may be a compromise between different parts of the zone. For finer-scale applications, fire behavior fuel model mapping rules should be locally critiqued whenever possible. We recommend doing this in a workshop setting, where local specialists with expertise in local fire behavior critique the national mapping rules and make adjustments as needed. Remember, the objective is to choose the fire behavior fuel model that most appropriately simulates the observed or expected fire behavior under a range of fire-environment conditions. It is therefore invaluable to have workshop participants who have seen fire burn under a range of conditions in the local vegetation types.

Another consideration common in more arid locations is whether the fuel models that are appropriate under a typical, or average, yearly weather scenario are appropriate in an atypical scenario. For example, in a typical year, fire behavior in many desert ecosystems may be best represented using a shrub fire behavior fuel model. However, in a year when an unusually wet winter is followed by an influx of annual grasses, the primary carrier of fire will be the herbaceous component and thus fire behavior would be better represented using a grass or grass-shrub fuel model. In this case, two separate versions of fuel data layers could be created to represent the different fuel scenarios.

Similarly, areas with a heavy deciduous tree component may experience very different fire behavior depending on the time of year. In fall, winter, and spring the leaves have fallen from deciduous trees, therefore adding to the load and structure of the surface fuels and associated surface fire behavior. As mentioned above, in deciduous forest vegetation types, LANDFIRE assigns pseudo canopy-fuel values that prohibit the simulation of crown fire in fire behavior modeling systems but retain the actual forest canopy cover and height values for modeling the influence of canopy cover on wind-reduction and fuel moisture. However, in mixed deciduous-conifer existing vegetation types LANDFIRE does not account for the proportion of deciduous-to-conifer cover; canopy bulk density is estimated from the total forest canopy cover. Depending on the proportion of conifer and deciduous trees, canopy bulk density may therefore be overestimated in these stands throughout the year, and wind-reduction and shading may be overestimated during the leaf-off times of the year.

Disturbance

Disturbances may affect both surface and canopy fuels depending on their type and severity. As with undisturbed fuels, the fuel mapping rules for disturbed areas should be critiqued by local fire specialists before application to finer-scale analyses.

In grass and shrub vegetation types the post-disturbance fire behavior fuel model is influenced by the affected species' response to disturbance. For example, wildfire in grass vegetation types is typically high-severity by nature—consuming all of the above-ground biomass. Most grasses, however, return to their pre-fire condition relatively quickly (i.e., one or two growing seasons) and in some cases will respond with increased biomass compared to the pre-fire condition due to an influx of nutrients and more favorable growing conditions. In shrub vegetation types, low-severity fire (less than 25% overstory mortality) may have little effect on the fuel load, fuelbed depth, and other components of a shrub-based fire behavior fuel model, whereas high-severity fire (greater than 75% overstory mortality) may result in immediate resprouting of shrubs or conversion to grass for some period of time, all dependent on the particular species' response to fire.

In tree-dominated vegetation types, low-severity fire will, generally speaking, consume litter (small dead branches and needles on the forest floor) and grass with minimal effect on understory shrubs and small trees. Moderate-severity fire may have a wide range of effects on litter and understory vegetation, but at the pixel level can generally be assumed to have consumed most of the litter and understory vegetation. By LANDFIRE severity definitions, moderate-severity fire in forested vegetation types results in 25% to 75% overstory tree mortality. High-severity fire results in greater than 75% mortality of the overstory trees. The mortality of overstory trees will influence the availability of light, water, and nutrients to understory vegetation, as well as contribute litter (through needle and branch fall) and large woody debris (as dead trees fall) as surface fuels over time.

These same principles apply to non-fire disturbance types. Ask yourself what is the response of the vegetation to the particular disturbance, what influences will this response have on post-disturbance fuel, how fire burns in the disturbed area, and what is the effect of time-since-disturbance.

As discussed in Chapter 3, the generalization of mechanical disturbance types to two categories—mechanical add and mechanical remove—may lead to a misrepresentation of effects. Critique of the LANDFIRE events polygon and individual year disturbance data by local experts can often confirm or provide additional information about the disturbance's effect on fuels.

The effect of time-since-disturbance varies by location and fuel type. Time-since-disturbance is split into three categories, the first of which is "one year". The need for the one year time-since-disturbance category can be evaluated based on your location, how you plan to apply the data, and how frequently you plan, or need, to update it.

Modeling

In-depth discussion of wildfire behavior modeling concepts is beyond the scope of this guidebook. Scott (2012) provides a comprehensive review of the topic in his *Introduction to Wildfire Behavior Modeling* guide. Nevertheless, a few considerations warrant discussion here. Wildfire behavior modeling requires an understanding of how the interaction among vegetation, fuels, and topography—as characterized in LANDFIRE data—influences modeling results. Wildfire analyst support may therefore be desired when critiquing and updating fuel data, depending on local wildfire behavior modeling expertise.

First, there is no direct, repeatable method for measuring canopy base height in the field, and multiple observers will often estimate significantly different values in the same stand. Methods exist to indirectly estimate canopy base height from plot data (Sando and Wick 1972; Cruz et al. 2003; Reinhardt and Crookston 2003; Scott and Reinhardt 2005), but canopy base height is challenging to map at a landscape scale because it is not well-related to characteristics that can be measured by remote sensing techniques. Canopy base height may include ladder fuels such as lichen, dead branches, needle drape, small trees, and shrubs. However, if shrubs and small trees are being considered as part of the fire behavior fuel model, they should not also be included in the canopy base height.

Next, understanding the interaction of fire behavior fuel model and canopy base height on modeling results is crucial in critiquing fuel data. The fire behavior fuel model predicts the surface fire intensity under a given set of environmental conditions (e.g., wind speed, slope steepness, fuel moisture). The lower the canopy base height, the milder these conditions can be in order to initiate crown fire. Given the difficulty of measuring and mapping canopy base height, working backwards— that is, adjusting canopy base height based on the conditions expected to initiate crown fire—is an effective way to critique canopy base height in relation to other variables. Tools such as NEXUS (Scott 1999) and BehavePlus (Andrews 2013) can provide information on the torching index—20' wind speed required for crown fire initiation—under various fuel and fire environments. The LFTFC tool also includes an option for calculating the critical canopy base height needed for crown fire initiation for different combinations of fire behavior fuel model, fuel moisture, and wind speed (Figure 16).

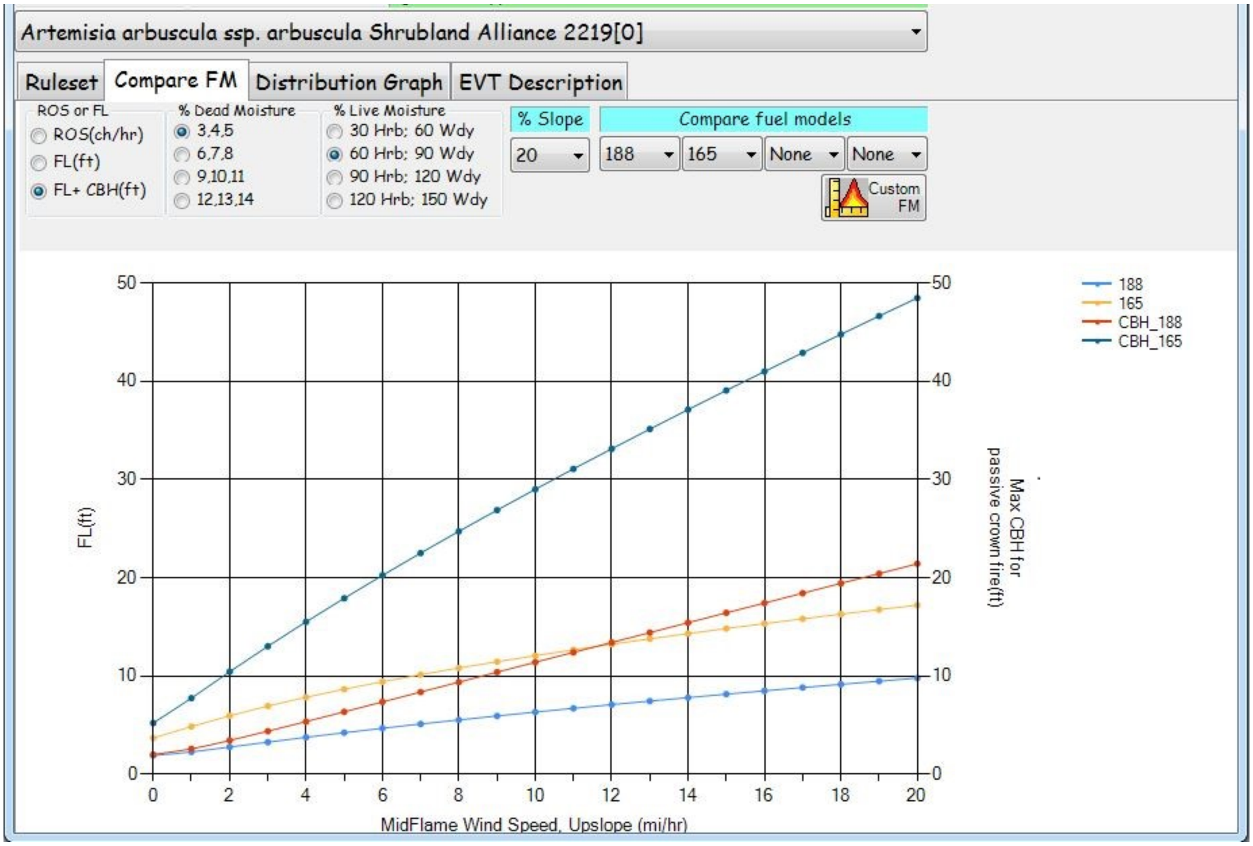


Figure 16. LANDFIRE Total Fuel Change Tool compare fuel model tab. This allows the user to calculate the critical canopy base height needed for crown fire initiation for different combinations of fire behavior fuel model, fuel moisture, and wind speed.

Lastly, in fire behavior modeling, canopy bulk density is a factor in determining whether an active crown fire can be sustained once initiated. Since the existing vegetation height classes used to predict canopy bulk density are rather coarse, they influence the resulting precision of the canopy bulk density values as well. Again, tools such as NEXUS and BehavePlus can be useful in determining if the data will predict the expected fire behavior under various conditions. Analysts are also encouraged to run geospatial fire behavior modeling systems to see if patterns in the results reveal any potential calibration issues that warrant a closer look. This is the *analyze* component of the data critique and modification framework discussed in Chapter 2.

Chapter 6: Fire Regime and Vegetation Departure

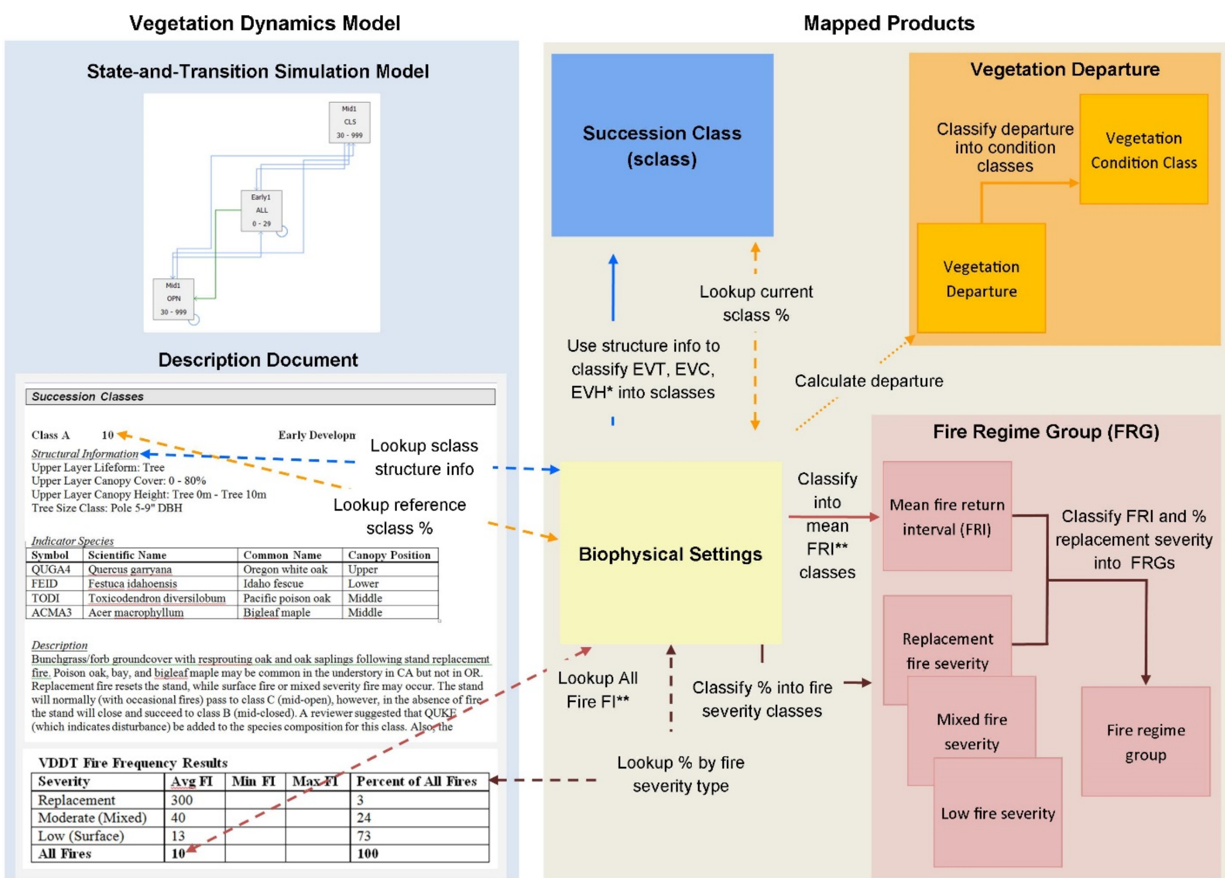
The fire regime and vegetation departure products are useful for understanding historical fire regimes and the current condition of vegetation on the landscape within the context of the historical disturbance regime. The fire regime products include fire regime group, mean fire return interval, percent low-severity fire, percent mixed-severity fire, and percent replacement-severity fire. The vegetation departure products include vegetation departure and vegetation condition class. The departure products were created for the LANDFIRE National, 2001, 2008 and 2012 versions but not for LANDFIRE 2010.

This chapter begins with an overview of the vegetation dynamics models, which form the basis of the fire regime and vegetation departure products, and then describes how those products are mapped by LANDFIRE. The chapter concludes by presenting common considerations for critiquing these data layers and provides examples of common pitfalls.

Fire Regime Mapping Process

Vegetation Dynamics Models

The foundation of the fire regime and vegetation departure products is a set of models that describe the vegetation dynamics and reference conditions of each biophysical setting mapped by LANDFIRE (Figure



*Existing vegetation type (EVT), cover (EVC) and height (EVH)
**Fire Interval (FI) and Fire Return Interval (FRI) refer to the average fire frequency modeled.

17). This section therefore begins with a brief overview of the models and how they relate to the fire regime and vegetation departure products. More information on the vegetation dynamics models can be found on the LANDFIRE program website.

Figure 17. The fire regime and vegetation departure products are created through crosswalks that link each BpS on the BpS data layer to the reference condition values modeled in the corresponding vegetation dynamics model.)

LANDFIRE collaborated with vegetation and fire ecology experts to create a vegetation dynamics model to estimate the reference (i.e., pre-Euro-American settlement) condition for each biophysical setting. The models were created in the Vegetation Dynamics Development Tool (VDDT, ESSA Technologies Ltd. 2007). A model represents a single biophysical setting and consists of five or fewer successional states, or classes, that compose the biophysical setting (Figure 18). Each state is equivalent to a succession class and each succession class is mapped in the succession class data layer (Chapter 4). A state has an age range that indicates how long it typically persists before it transitions to the next state. Disturbance pathways between states are used to represent the impact of important disturbances, and each pathway is defined by a probability that describes how often it occurs. The models were attributed based on scientific literature, available data, and the experience and judgment of the modelers (Rollins 2009).

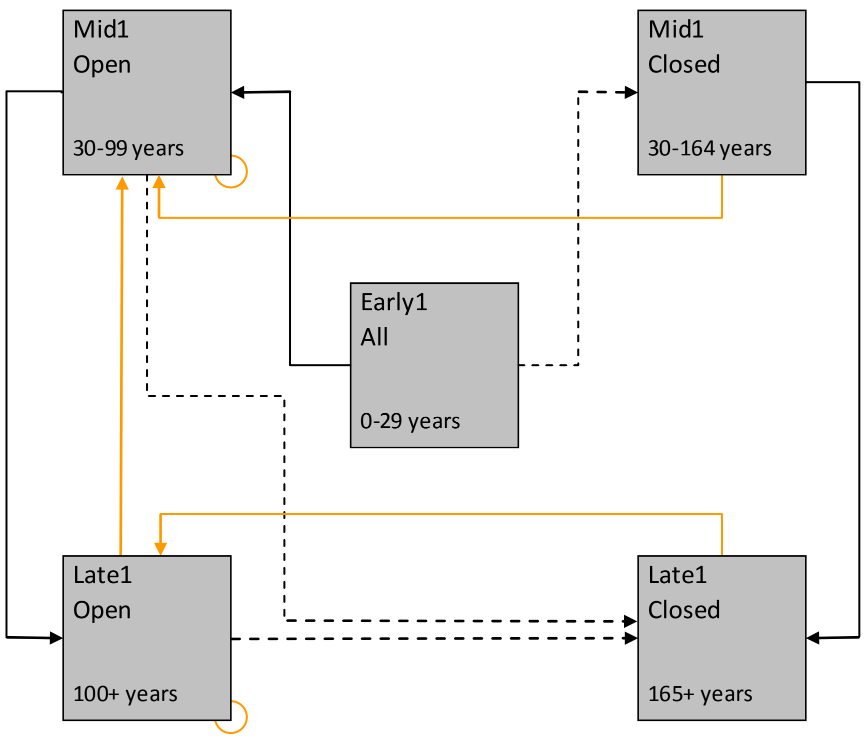


Figure 18. State-and-transition model of the Pacific Northwest Mixed Conifer BpS. This model is comprised of five successional states (boxes). Each state has an age range and is linked to other states through main successional pathways (solid lines), alternative succession pathways (dashed lines) and disturbance pathways (yellow line represent mixed fire transitions).

Once attributed, each model was run for ten 1,000-year simulations, in VDDT, and the results were averaged to estimate the biophysical setting reference conditions. The reference conditions include:

- the fire frequency expressed as a mean fire return interval,

- the fire severity expressed as the relative percent of low-, mixed-, and replacement-severity fire, and
- the relative amount represented by each succession class expressed as a percent.

The reference conditions are published in the LANDFIRE model descriptions along with the VDDT models available from the LANDFIRE website (Figure 19).

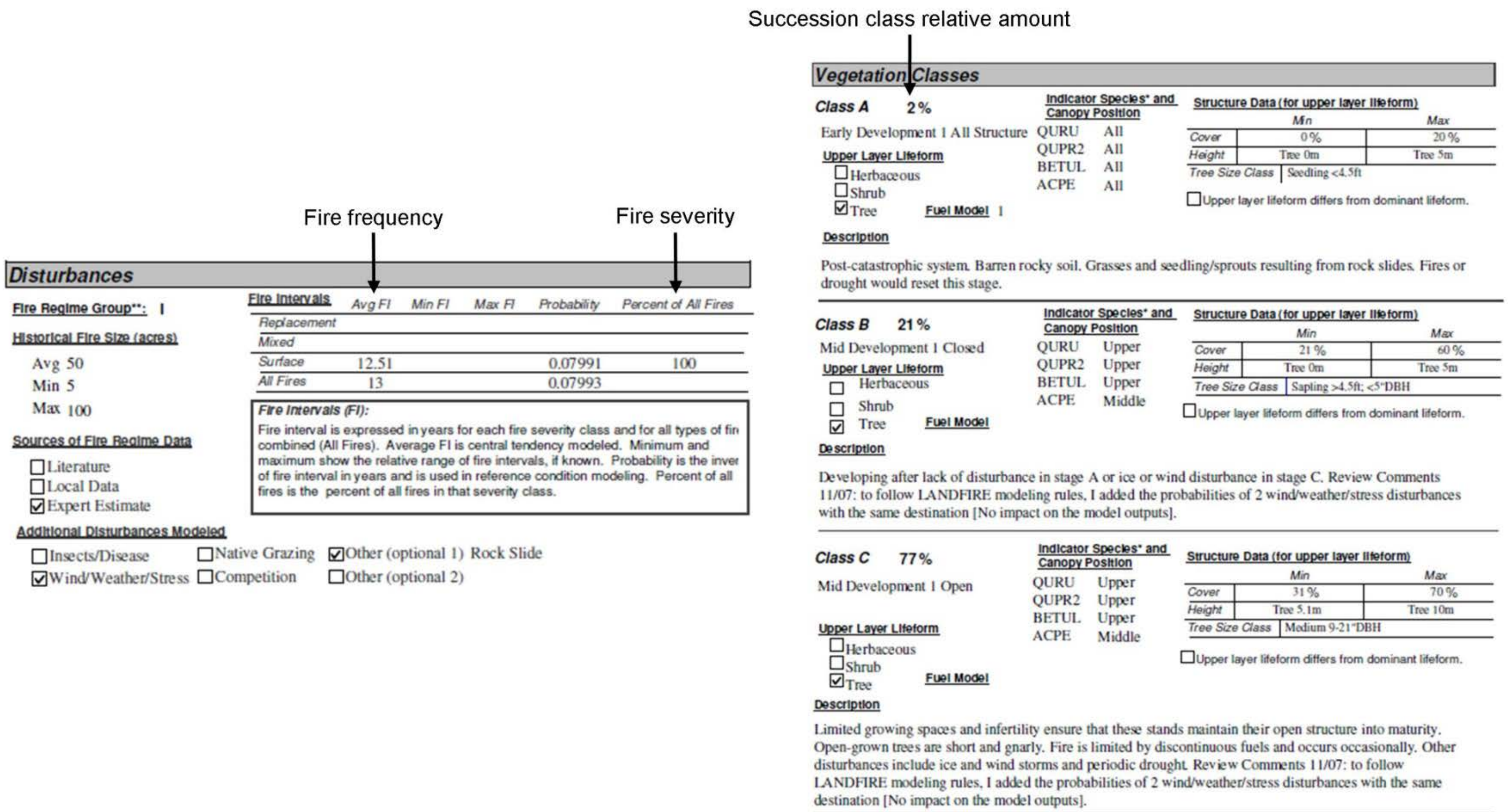
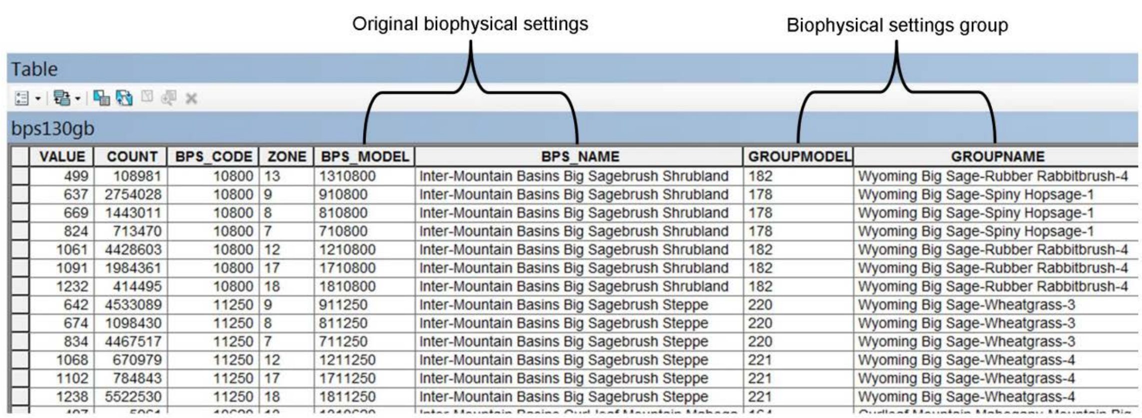


Figure 19. The biophysical setting model descriptions contain the reference conditions. The fire frequency and severity are found in the Disturbances section. The relative amount represented by each succession class is expressed as a percent and is found after the class letter name in the upper left of each vegetation class description.

Vegetation Dynamics Models and Biophysical Setting Map Units

The LANDFIRE biophysical setting data layer contains attributes for two nested map units: biophysical setting and biophysical setting groups. The biophysical setting attribute is the original biophysical setting classification based on NatureServe's Ecological Systems and described in the vegetation dynamics model description documents. LANDFIRE created biophysical setting groups to simplify the mapping of the fire regime products and to reduce the complexity of the vegetation dynamics model set for users. The original units were placed into groups based on similar vegetation and fire regime characteristics. Each biophysical setting group is represented by a single "exemplar" model chosen from the original model set. The fire regime products and the succession class data layer in LANDFIRE 2001 and 2008 are based on the biophysical setting groups and their associated exemplar models. All other LANDFIRE versions, including the most recent versions, use the original biophysical setting attribute. Although the biophysical setting and the biophysical setting groups are related, they can have different succession class definitions and different reference conditions, including different succession class proportions and fire frequency and severity values. Users need to pair the correct biophysical setting attribute in the biophysical setting data layer with the correct model based on the version of LANDFIRE data they are using. The relationship between biophysical setting and biophysical setting groups is described in the "BpS Groups Table" located on the LANDFIRE website (Figure 20).



VALUE	COUNT	BPS_CODE	ZONE	BPS_MODEL	BPS_NAME	GROUPMODEL	GROUPNAME
499	108981	10800	13	1310800	Inter-Mountain Basins Big Sagebrush Shrubland	182	Wyoming Big Sage-Rubber Rabbitbrush-4
637	2754028	10800	9	910800	Inter-Mountain Basins Big Sagebrush Shrubland	178	Wyoming Big Sage-Spiny Hopsage-1
669	1443011	10800	8	810800	Inter-Mountain Basins Big Sagebrush Shrubland	178	Wyoming Big Sage-Spiny Hopsage-1
824	713470	10800	7	710800	Inter-Mountain Basins Big Sagebrush Shrubland	178	Wyoming Big Sage-Spiny Hopsage-1
1061	4428603	10800	12	1210800	Inter-Mountain Basins Big Sagebrush Shrubland	182	Wyoming Big Sage-Rubber Rabbitbrush-4
1091	1984361	10800	17	1710800	Inter-Mountain Basins Big Sagebrush Shrubland	182	Wyoming Big Sage-Rubber Rabbitbrush-4
1232	414495	10800	18	1810800	Inter-Mountain Basins Big Sagebrush Shrubland	182	Wyoming Big Sage-Rubber Rabbitbrush-4
642	4533089	11250	9	911250	Inter-Mountain Basins Big Sagebrush Steppe	220	Wyoming Big Sage-Wheatgrass-3
674	1098430	11250	8	811250	Inter-Mountain Basins Big Sagebrush Steppe	220	Wyoming Big Sage-Wheatgrass-3
834	4467517	11250	7	711250	Inter-Mountain Basins Big Sagebrush Steppe	220	Wyoming Big Sage-Wheatgrass-3
1068	670979	11250	12	1211250	Inter-Mountain Basins Big Sagebrush Steppe	221	Wyoming Big Sage-Wheatgrass-4
1102	784843	11250	17	1711250	Inter-Mountain Basins Big Sagebrush Steppe	221	Wyoming Big Sage-Wheatgrass-4
1238	5522530	11250	18	1811250	Inter-Mountain Basins Big Sagebrush Steppe	221	Wyoming Big Sage-Wheatgrass-4

Figure 20. LANDFIRE biophysical settings were placed into groups based on similar vegetation and fire regime characteristics. Each biophysical setting group is represented by a single "exemplar" model chosen from the original model set. For example, in the table above notice that the seven original Inter-Mountain Basins Big Sagebrush Shrubland biophysical settings models were lumped into two groups: Wyoming Big Sage-Rubber Rabbitbrush-4 and Wyoming Big Sage-Spiny Hopsage-1.

Fire Regime: Frequency, Severity, and Fire Regime Group

The mean fire return interval data layer depicts the presumed historical fire frequency for each biophysical setting. The layer is created by linking the biophysical setting to the VDDT-modeled fire frequency results described in the vegetation dynamics model description document. The mean fire return interval is classified into 22 categories that vary in length to provide greater temporal resolution for frequently burned biophysical settings and less temporal resolution for biophysical settings that burn infrequently.

The fire severity data layers depict the relative percent of low-, mixed-, and replacement-severity fire under the presumed historical fire regime for each biophysical setting. Fire severity is defined as the percent mortality of the overstory vegetation: less than 25% mortality is classified as low-severity, 25-75% mortality is classified as mixed-severity, and greater than 75% mortality is classified as high-severity. The layer is created by linking the biophysical setting to the VDDT-modeled relative amount of each fire severity type as reported in the vegetation dynamics model description document. The results range from 0-100% and they are classified and mapped in 5% increments.

The fire regime group data layer characterizes the presumed historical fire frequency and percent replacement severity fire for each biophysical setting in five classes (Table 8). The fire regime group layer is created by linking the biophysical setting to the fire frequency and severity results described in the vegetation dynamics model description document.

Table 8: Fire regime group mapping rules. The fire regime group layer is created using a rule set that classifies combinations of fire frequency and relative percent replacement severity fire into one of five fire regime groups for each biophysical setting.

Fire Regime Group	All Fire Frequency (years)	Relative Percent Replacement Severity Fire
I	0-35	<66%
II	0-35	>=66%
III	36-100	<80%
	101-200	<66%
IV	36-100	>=80%
	101-200	>=66%
V	>=201	Any fire severity

All of the fire regime products include additional map units for water, snow/ice, barren, and sparsely vegetated systems which are mapped from the existing vegetation type data layer. The value "indeterminate fire regime characteristics" identifies a biophysical setting without fire disturbance in its associated vegetation dynamics model. These are typically biophysical settings that are either too wet or too dry to carry fire (e.g., Alaskan Pacific Maritime Sitka Spruce Forest biophysical setting).

Vegetation Departure

LANDFIRE provides geospatial data that characterize two metrics of vegetation departure: stratum vegetation departure and stratum vegetation condition class. Vegetation departure and vegetation condition class are calculated following the methodology described in the FRCC Guidebook (Barrett et al. 2010) and the FRCC Mapping Tool User's Guide (Jones and Ryan 2012). Both metrics describe the overall departure of the current vegetation conditions from the historical, or reference, vegetation conditions across all succession classes within a particular biophysical setting (i.e., stratum). The historical proportion, or relative amount, of each succession class in a biophysical setting is based on the average proportion modeled in the vegetation dynamics model and reported in the model description document (Figure 17). Current succession class proportions are calculated directly from the succession class data layer.

Stratum vegetation departure is calculated by determining the succession class "similarity" (the smaller of the reference, or the current proportion, for each succession class), summing the similarities, and then subtracting from 100. This provides the percent departure for a biophysical setting and that value is mapped in the vegetation departure data layer. To create the vegetation condition class data layer, the percent departure is classified into three classes: 0-33% departure in condition class 1, 34-66% departure in condition class 2, and 67-100% departure in condition class 3 (see sidebar).

Calculating Vegetation Departure

Stratum vegetation departure is calculated by comparing the reference distribution of succession classes (i.e., the proportion that each contributes to the whole expressed as a percent) to the current distribution of succession class for individual biophysical settings. In the table below, departure is calculated for a biophysical setting with three reference succession classes (A, B, and C), which are defined in its vegetation dynamics model. The Uncharacteristic succession class only includes a current value because by definition it does not occur under the reference condition. The uncharacteristic class proportion is the sum of the uncharacteristic native and uncharacteristic exotic proportions.

The first step in calculating stratum vegetation departure is to determine the succession class similarity (i.e., the lower of the reference or current percent) of each succession class. Next, stratum similarity is calculated by summing the succession class similarity values. Then, the current stratum vegetation departure is calculated by subtracting the stratum similarity value from 100. This is the value mapped in the LANDFIRE vegetation departure grid. Finally, the vegetation condition class is calculated by classifying the current stratum vegetation departure value into the three condition classes (1 = ≤ 33%, 2 = > 33% to ≤ 66%, 3 = > 66%). This is the value mapped in the LANDFIRE Vegetation Condition Class grid:

Succession Class (S-Class)	Reference Percent	Current Percent	S-Class Similarity
A-Early	15	3	3
B-Mid	40	25	25
C-Late	45	31	31
Uncharacteristic	0		
Stratum Similarity	**59**		
Current Departure	**41**		
Vegetation Condition Class	**2**		

Departure is calculated for a specific geographic area referred to as the landscape summary unit. For LANDFIRE National, departure was calculated for ecological subsections (Cleland et al. 2005) within a LANDFIRE map zone. In LANDFIRE 2001 and 2008 departure was calculated within nested hydrologic unit codes (HUCs; Seaber et al. 1987). Departure for biophysical settings in fire regime groups I and II was calculated at the sub-watershed level (HUC 12); biophysical settings in fire regime group III were calculated at the watershed level (HUC 10); and biophysical settings in fire regime groups IV and V were calculated at the sub-basin level (HUC 8). In LANDFIRE 2012 the landscape summary unit was defined as a biophysical setting with identical reference condition values regardless of map zone. To understand this, imagine that a biophysical setting is mapped in map zones 1, 2, and 3 and that zones 1 and 2 have identical reference conditions in their associated vegetation dynamics models but that zone 3 has a unique set of reference conditions. In this case, the departure would be calculated using the biophysical setting's extent in zones 1 and 2 as one summary unit and zone 3 as another summary unit.

Considerations

Understanding the Source Data

All of the fire regime and vegetation departure products are derived from other LANDFIRE products. Any assumptions, limitations, and issues associated with the source data are inherited by the fire regime and vegetation departure products. To understand and critique these products, the user must therefore understand the source data. The fire frequency, fire severity, and fire regime group values come from the vegetation dynamics models. Vegetation departure and vegetation condition class results are derived from the modeled reference conditions, the biophysical setting data layer, the succession class data layer, (which is itself derived from the biophysical setting, existing vegetation type, existing vegetation cover, and existing vegetation height data layers; see Chapter 4), and the landscape summary unit. The information from other chapters in this guide will help the user critique these geospatial data inputs. For more information on critiquing the vegetation dynamics models, refer to the *Reviewing and Modifying LANDFIRE Vegetation Dynamics Models* (The Nature Conservancy 2011a) user's guide.

Knowledge Uncertainty

The quality of the fire regime and vegetation departure products depends to a great extent on the quality and quantity of the information used to create the vegetation dynamics models. In general, there are more data to attribute models for economically valuable and heavily studied biophysical settings, such as forested ecosystems, than there are for biophysical settings with little economic value and those that are rare (Blankenship et al.2012). The quantity and quality of fire regime information also varies considerably based on the characteristics of the vegetation comprising the biophysical setting. Fire history from recent centuries tends to be most reliably documented in systems where the evidence of low- and moderate-severity fires is recorded and persists within the annual rings of long-lived tree species (Swetnam et al. 1999) such as longleaf pine and ponderosa pine, and/or where the time since the last stand-replacing fire can be determined from the stand age. In non-forested systems, little direct evidence persists for inferring the characteristics of historical fire regimes (Swetnam et al. 1999) although historical records, charcoal and pollen records, and dependence or sensitivity of long-persisting species provide clues to the fire frequency and severity. The vegetation dynamics model description documents often provide information about the sources and the quality of the information on which they are based and can provide users with valuable information for evaluating the fire regime products derived from them.

Map Zone Boundaries

The vegetation dynamics models were developed to apply at the level of a LANDFIRE map zone (Figure 2). Sometimes the same biophysical setting may have different succession class mapping rules, succession class reference proportions, and fire frequency and severity information in different map zones. This can lead to abrupt changes in the fire regime and vegetation departure products at map zone boundaries, even for the same biophysical setting. Users performing an independent departure analysis can address this issue (see Vegetation Departure Analysis below).

Changes in Departure Methods

The methods LANDFIRE used to create the departure products have changed between versions (Table 9). Users should be cautious when comparing the departure products (vegetation departure and vegetation condition class) between different LANDFIRE versions because changes in the biophysical setting map units and the landscape summary unit discussed above, as well as the source of the reference conditions, can change the departure score. Theoretically the LANDFIRE 2001 and 2008 departure data layers are comparable because they were calculated using the same method, but it may be too short a time period to see substantial change across broad areas. LANDFIRE 2001, 2008 and 2012 departure data layers are not comparable to LANDFIRE National because of the changes in the methods (USFS [n.d.] Fire Regime Data…).

Table 9: Comparison of the methods and input data used to create the LANDFIRE departure data products by data version.

Version	Departure Products Mapped	Departure BpS Unit[a]	Summary Unit	Reference Condition Source[b]
National	Yes	BpS	Ecological Subsections within Mapzones	VDDT & LANDSUM
2001	Yes	BpS Group	Nested Hydrologic Unit Codes	VDDT
2008	Yes	BpS Group	Nested Hydrologic Unit Codes	VDDT
2012	No	BpS	Unique Combination of BpS Code and BpS Model	VDDT

[a]Vegetation departure products were calculated for the biophysical setting (BpS) or the BpS groups depending on the version. In versions where departure products were not mapped, the Departure BpS Unit refers to the units used to map the fire regime and succession class layers.
[b]The reference conditions were derived from the Vegetation Dynamics Development Tool (VDDT) and the Landscape Succession Model (LANDSUM). For LANDFIRE versions 2001 and greater the reference condition source is as described in this guide. The reference conditions source for the National version is described in the document "Developing the LANDFIRE Fire Regime Data Products" on the LANDFIRE Program website.

Vegetation Departure Analysis

Rather than use the LANDFIRE vegetation departure products as-is, many users prefer to complete their own, local, departure analysis. Performing an independent departure analysis allows users to address the issues discussed above, critique and refine the succession class mapping rules, and integrate ancillary data (e.g., locally mapped invasive species distribution). The Fire Regime Condition Class Mapping Tool also allows for the calculation of additional vegetation departure metrics beyond stratum vegetation departure and stratum vegetation condition class, as well as fire *regime* departure analysis. In addition to the considerations listed above, there are some considerations specific to an independent departure analysis using LANDFIRE data.

Biophysical Setting Thematic Resolution

Users performing an independent departure analysis may want to consider the thematic resolution (Chapter 1) of the biophysical setting data layer in relation to their analysis objectives (Chapter 2), especially if there are concerns about the source data or knowledge uncertainty as discussed above. Using the biophysical setting group attribute is one way to "coarsen" the biophysical setting data layer to a more appropriate thematic resolution, but careful critique of the "exemplar" vegetation dynamics model associated with the biophysical setting group is critical. In some cases, the user may want to choose a different "exemplar" model that better represents the biophysical setting group for their analysis location.

Biophysical setting classes may also be grouped using local, ancillary information. For example, in a vegetation condition analysis of Southern Sierra National Forests, analysts grouped models based on similarity of vegetation characteristics and fire regimes following a crosswalk between LANDFIRE biophysical setting and presettlement fire regime groups presented in Van De Water and Safford (2011), thus reducing the number of biophysical settings from 25 to 15.

If biophysical settings are grouped to coarsen the thematic resolution of the biophysical setting data layer, the user will usually be required to manually map succession class due to differences in succession class definitions between the original and chosen vegetation dynamics models. The guide *How to Map Successional Stages Using LANDFIRE Products* (The Nature Conservancy 2013) provides step-by-step instructions on how to do this.

Biophysical Settings that Cross Map Zone Boundaries

In situations where the analysis area overlaps more than one LANDFIRE map zone, a primary consideration is whether there are differences in the vegetation dynamics models between zones, and if such differences reflect reality. If the map zone boundary reflects an ecological transition, then differences between models for the same biophysical setting may be acceptable and necessary. However, if the map zone boundary creates an artificial demarcation in the analysis area, users will want to choose the model that best fits the analysis area and make the appropriate modifications to the related geospatial data. If a new biophysical setting model is chosen, the succession class data layer will need to be adjusted so that it reflects the succession class mapping definitions of the new model (the guide *How to Map Successional Stages Using LANDFIRE Products* provides instructions for re-mapping succession classes) (The Nature Conservancy 2013).

Succession Class Mapping Rules

It is particularly important to critique the succession class mapping rules because the vegetation departure calculation is very sensitive to the amount of area mapped to each succession class. The LANDFIRE succession class data layer is created by applying rule sets to combinations of biophysical setting, existing vegetation cover, existing vegetation height, and to a lesser extent existing vegetation type (Chapter 4). Any problems in the input data layers will carry through to the succession class data layer. Three general concerns with the succession class mapping rules that can impact departure assessments are: 1) the mappability of the classes; 2) the completeness of the succession class rule set; and, 3) the classification of uncharacteristic types.

> *Mappability of Succession Classes*. Succession class is a concept that can be difficult to translate into mappable criteria. Height and cover, the primary variables LANDFIRE uses to map succession class, may not always be the best surrogate for vegetative development and can be difficult to map (Chapter 4). In particular, the height classes for shrub and herbaceous lifeforms are difficult to discern using LANDFIRE's two dimensional satellite imagery. For example, it may be difficult to distinguish 0.5m tall grass from 1.0m tall grass using Landsat data, but some succession classes are mapped based on this distinction. In forests, the height classes tend to be mapped more accurately (see Chapter 4 - Existing Vegetation), but they may be too coarse to adequately differentiate succession classes (e.g., 10 to 25m and 25 to 50m).
>
> *Completeness of the Rule Set.* Ideally, the succession class rule sets would cover all possible mapped combinations of existing vegetation type, existing vegetation cover, and existing vegetation height for every biophysical setting without gaps or overlaps. In other words, the rules should be mutually exclusive and exhaustive, but this is not the case for all LANDFIRE succession class rules.

Take, for example, a hypothetical shrub biophysical setting with two succession classes defined as follows:

A - shrubs 10-100% cover and height < 1m

B – shrubs 50-100% cover and height > 0.5m

In this case shrubs .5-1m tall with >50% cover could be classified in either succession class A or B; the rule set is not mutually exclusive.

Take another hypothetical example of a tree-dominated biophysical setting:

A – trees 0-100% cover and < 5m height; or herbs or shrubs 0-100% cover and “any” height

B – trees 0-100% cover and 5-10m height

C – trees 0-100% cover and 10-25m height

In this example, if trees are not established or trees are less than 5m in height, the pixel is mapped as succession class A. Trees that are 5-10m in height are mapped as succession class B and trees 10-25m in height are mapped to succession class C. What about trees greater than 25m in height? Did the model developers intend for this condition to be mapped as uncharacteristic? In many cases this is not the intent; rather, the rule was developed before the geospatial data were mapped and the modelers chose the most reasonable height class without knowledge of the possible mapped height range. When the rules are not exhaustive and/or mutually exclusive, pixels can be mapped into an inappropriate class.

Users also should watch for rules that overlap in structure (cover and height) but differ by species composition. Some vegetation dynamics model descriptions use existing vegetation type as criteria for distinguishing between succession classes, but it was not a primary variable used in mapping—although this varies by biophysical setting and data version. In these cases the succession class assigned by LANDFIRE may not be in agreement with the vegetation dynamics model description. For example, in LANDFIRE map zone 21, the Rocky Mountain Aspen Forest and Woodland vegetation dynamics model differentiates between succession classes C and E by species composition (Figure 12). Both classes have the same structural criteria but succession class C represents a “relatively pure aspen stand,” whereas succession class E represents “aspen replaced by other vegetation types or a mixed aspen-conifer overstory that is changing to a conifer dominated forest.” These classes should be differentiated by existing vegetation type, but as recent as LANDFIRE 2010 no pixels were mapped to succession class E because existing vegetation type was not used in the succession class mapping process.

If manually mapping succession class, the existing vegetation type data layer can be used to mitigate this issue. For instance, where the structural criteria are met, succession class C would be assigned to pixels classified as the Rocky Mountain Aspen Forest and Woodland existing vegetation type; succession class E would be assigned to pixels classified as an aspen-mixed conifer or a pure conifer existing vegetation type.

Classification of Uncharacteristic Types. LANDFIRE classifies uncharacteristic vegetation as either uncharacteristic native or uncharacteristic exotic (Chapter 4). The uncharacteristic native class indicates that the existing characteristics (i.e., cover, height, and composition) of native vegetation are outside the reference condition range. When conducting a local vegetation departure analysis users may want to critique the mapping rule thresholds for local relevance. For example, if the maximum canopy cover in the vegetation dynamics model is 40%, any cover greater than 40% will be mapped as uncharacteristic native. Does local research of reference conditions corroborate the 40% threshold? Another instance in which the succession class might be mapped as uncharacteristic native is when a *native* riparian existing vegetation type is mapped to a non-riparian biophysical setting. As discussed in Chapter 4 this situation may be due to differences in the mapping methodologies for biophysical setting and existing vegetation type (see Chapter 4 - Potential vs. Existing Vegetation Type Rectification). Users may wish to further critique the data in such situations.

The uncharacteristic exotic class indicates that an exotic species has become established in an area. Succession class is mapped as uncharacteristic exotic wherever an "introduced" existing vegetation type is mapped (e.g., introduced upland vegetation-perennial grassland and forbland). A consideration related to the presence of exotic species is that LANDFIRE classifies less than 10% vegetation cover as "sparsely vegetated." For some analysis objectives, it may be important to identify sparse cover of exotics, such as cheatgrass (*Bromus tectorum)*, and this may require ancillary data sources (Provencher et al. 2009).

Landscape Summary Unit

Independent vegetation departure analyses are not tied to the landscape summary units used by LANDFIRE. The key criterion for landscape delineation is that the summary unit needs to be large enough to encompass the full range of succession classes expected under the historical disturbance regime (Barrett et al. 2010). Careful consideration should be given to the choice of the landscape summary unit using the guidance in the Fire Regime Condition Class Guidebook and Fire Regime Condition Class Mapping Tool User's Guide, keeping in mind that departure scores may vary with changes in the summary unit. If the landscape summary unit is so small that it would not contain the full range of succession classes under the historical disturbance regime, misleading departure scores can result, and lead to errors in the subsequent planning process (Barrett et al. 2010). In contrast, summary units that are too large may make it difficult to discern changes in departure due to planned (e.g., restoration treatments) and unplanned disturbances (Barrett et al. 2010). This may be the case for some biophysical settings under the LANDFIRE 2012 methodology for mapping departure, in which the full extent of the biophysical setting in one or multiple map zones is used as the summary unit to calculate departure. However, it is the intent of the off-the-shelf LANDFIRE products to assess departure at a much broader scale than that of a typical local analysis.

Chapter 7: Interpreted Examples

In this chapter, we (the authors) illustrate the data critique and modification process in two example applications. The first example critiques LANDFIRE data for use in fire behavior analysis of the Rogue Basin located in southwest Oregon (Figure 21). The second example focuses on the critique of LANDFIRE data for use in vegetation departure analysis in the southern Sierra Nevada Mountains of California (Figure 21).

Figure 21. Project area boundaries for interpreted examples.

There are multiple approaches and tools available for critiquing and modifying geospatial data. In these examples we demonstrate the use of common approaches and tools that are available to most natural resource professionals. The following examples summarize the concepts and considerations for modifying LANDFIRE data discussed in previous chapters and therefore should be beneficial to all readers regardless of expertise in working with geospatial data. Details on geospatial analysis and data manipulation tasks, however, are beyond the scope of this document and are only outlined here.

Example 1: Critiquing LANDFIRE data for local fire behavior analysis

Define objectives

For this example we turned to the 3.3 million-acre Rogue Basin in southwest Oregon, where the Southern Oregon Forest Restoration Collaborative and its partners are undertaking the development and implementation of a cohesive forest restoration strategy. A key component in the development of this strategy was an understanding of the current wildfire hazard and associated risk to the Basin's natural resources and assets. Our objective was to conduct a wildfire hazard analysis using LANDFIRE data and geospatial wildfire behavior modeling software.

Identify data requirements

Eight geospatial data layers are required inputs for simulating the full range of wildfire behavior—surface through active crown—in the geospatial fire modeling systems used in this analysis. These layers characterize surface fuels (fire behavior fuel model), canopy fuels (canopy base height and canopy bulk density), forest canopy structure (canopy cover and canopy height), and topography (elevation, aspect, and slope). Each geospatial data layer is available from LANDFIRE.

Given our objective to geospatially analyze wildfire hazard, it was important that the geospatial data represent the fuels and wildfire potential as appropriately as possible for the scale of the analysis. To evaluate the LANDFIRE fuels data we would use the LANDFIRE Total Fuel Change Tool (LFTFCT 2011), which allows for the critique, modification, and analysis of fuel mapping rules and their effect on simulated fire behavior within the tool itself. Because LANDFIRE fuel data (Chapter 5) are derived from existing vegetation type, cover, and height (Chapter 4), biophysical setting (Chapter 4), and disturbance (Chapter 3), the tool requires these geospatial data layers as input, thus increasing our data requirements. We downloaded the additional data layers using the LANDFIRE Data Access Tool (Figure 22, LFDAT 2012).

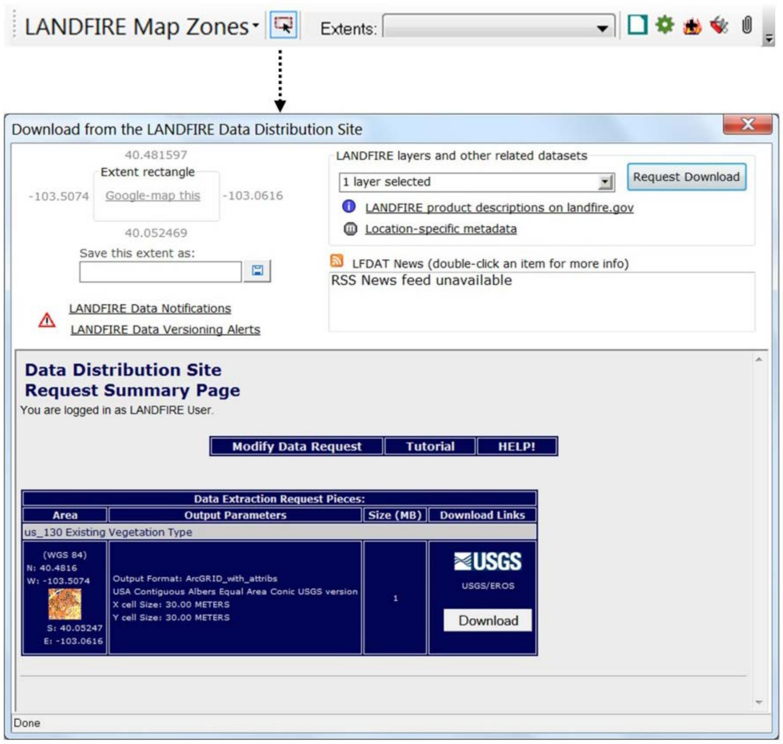


Figure 22. The LANDFIRE Data Access Tool (LFDAT). The LFDAT is a custom ArcGIS toolbar that links to the LANDFIRE Data Distribution Site.

Critique

The fundamental question of our critique was whether LANDFIRE data would be appropriate for simulating wildfire behavior at the analysis location and scale. The LANDFIRE Total Fuel Change Tool would be used to assess the fuel mapping rules in addressing this question; however, *data currency* and *map unit accuracy* (Chapter 1) are also important to accurately simulate the current wildfire hazard so we began our critique there.

The wildfire analysis component of this project began in January 2015, just after LANDFIRE version 1.3.0 (LANDFIRE 2012) data were released for the region. This meant the data were two years out-of-date at the time of acquisition. A critical first task was therefore to determine how much the landscape had changed in the preceding two years.

Approximately 200,000 acres of wildfire and 11,500 acres of mechanical disturbance had occurred over 2013 and 2014 within the wildfire simulation landscape. Given this information, it was clear that currency updates to the LANDFIRE vegetation and disturbance data inputs would be required prior to critiquing the fuel mapping rules with the LANDFIRE Total Fuel Change Tool.

The input data were also critiqued for map unit accuracy. Upon field review, local resource managers felt that oak woodland ecological systems were underrepresented in the LANDFIRE existing vegetation type data layer and that ancillary data would be required to address this issue. In critiquing the LANDFIRE disturbance data, local resource specialists also determined that certain disturbance type assignments were not correct for the local area. For example, the assignment of mechanical remove to all silvicultural treatments (i.e., clearcut, harvest, thinning) was not appropriate for the Rogue Basin because not all local harvesting methods are accompanied by activity-fuel treatments such as hand-pile burning or biomass extraction. Similarly, there were activities assigned to the “other mechanical” event type (a mechanical-add disturbance) that participants felt should be assigned to mechanical-remove. In addition, participants felt that although mastication event types add fuel to the surface fuelbed, they should be differentiated from the other mechanical add disturbances due to the effect of the structure and compactness of masticated fuel on fire behavior.

Finally, as discussed in Chapter 3, LANDFIRE does not currently use a cumulative effect approach to assign disturbance attributes in the composite fuel disturbance data layer. Rather, if multiple treatments occurred in the same location within the update period, the attributes of the most recent treatment are assigned (except where fire has occurred; see Chapter 3). This was also a potential cause of inaccurate map unit assignment.

To summarize, the following information was gathered from the data critique and used to modify the geospatial data inputs to the LANDFIRE Total Fuel Change Tool.

- Data is not current through 2014.
- Oak woodland ecological systems are underrepresented.
- Some disturbance type map unit assignments are inaccurate due to generalization of treatment types at the national scale and/or incorrect accounting of cumulative treatment effects.
- Grouping of mastication treatments with other mechanical add disturbances does not represent the unique fire behavior of masticated fuel.

Modify LANDFIRE Total Fuel Change Tool inputs

As discussed above, the LANDFIRE Total Fuel Change Tool requires geospatial data layers of: existing vegetation type, cover, and height; biophysical setting; and disturbance as inputs. The amount of updating required for these layers varies depending on analysis objectives. The following sections describe the modifications that were made, or why modification was determined to be unnecessary, for each of the required geospatial data layers based on our data critique.

Disturbance

Data Currency

Because the LANDFIRE 2012 composite fuel disturbance data layer only represents conditions through 2012, two data currency updates were required to create an up-to-date 2014 disturbance layer: 1) the time-since-disturbance attribute needed to be updated to reflect the two additional years that had passed, and 2) new disturbances—those that occurred in 2013 and 2014—would need to be added. The following methods were used to create the updated disturbance layer.

First, we determined the years for which the time-since-disturbance attribute would need to be updated (Table 6). Disturbances that occurred from 2005-2007 would remain in the 6-10 year time-since-disturbance class. Likewise, disturbances that occurred in 2010 and 2011 would remain in the 2-5 year time-since-disturbance class. However, disturbances that occurred in 2008 and 2009 would need to be updated to the 6-10 year class and disturbances that occurred in 2012 would need to be updated to the 2-5 year class.

The 2003 and 2004 disturbances would now be greater than ten years old. LANDFIRE removes disturbances greater than ten years old from the composite vegetation and fuel disturbance data layers (Chapter 3) and may also update existing vegetation layer map units to reflect a vegetation transition based on the ecology of the region. For example, a forested, existing vegetation type that experienced a high-severity wildfire, and was subsequently reassigned as an herbaceous or shrub existing vegetation type, may be reassigned to a forest vegetation type after ten years if reestablishment of trees is expected. More information on LANDFIRE vegetation transition rules is available on the program's website. Based on our analysis objectives we determined that we could leave the 2003 and 2004 disturbances in the 6-10 year time-since-disturbance class since we were only concerned with the fuel data layers required for wildfire hazard analysis and therefore not required to update existing vegetation layers.

Next, we downloaded the individual-year disturbance data layers for the years 2008-2012 using the LANDFIRE Data Access Tool. These layers were used to create two "geospatial masks" using the ArcGIS Spatial Analyst extension—one representing the 2008-2009 disturbances and one representing the 2010-2012 disturbances (Figure 23). Masks are used in geospatial analysis to constrain operations to certain pixels within a raster dataset. In our case, we used the masks to identify and update the time-since-disturbance of pixels where a disturbance had occurred in 2008 or 2009 without subsequent disturbances in 2010-2012. As in the LANDFIRE mapping process, if a fire disturbance occurred prior to 2008 we retained the time-since-disturbance of the fire (Chapter 3).

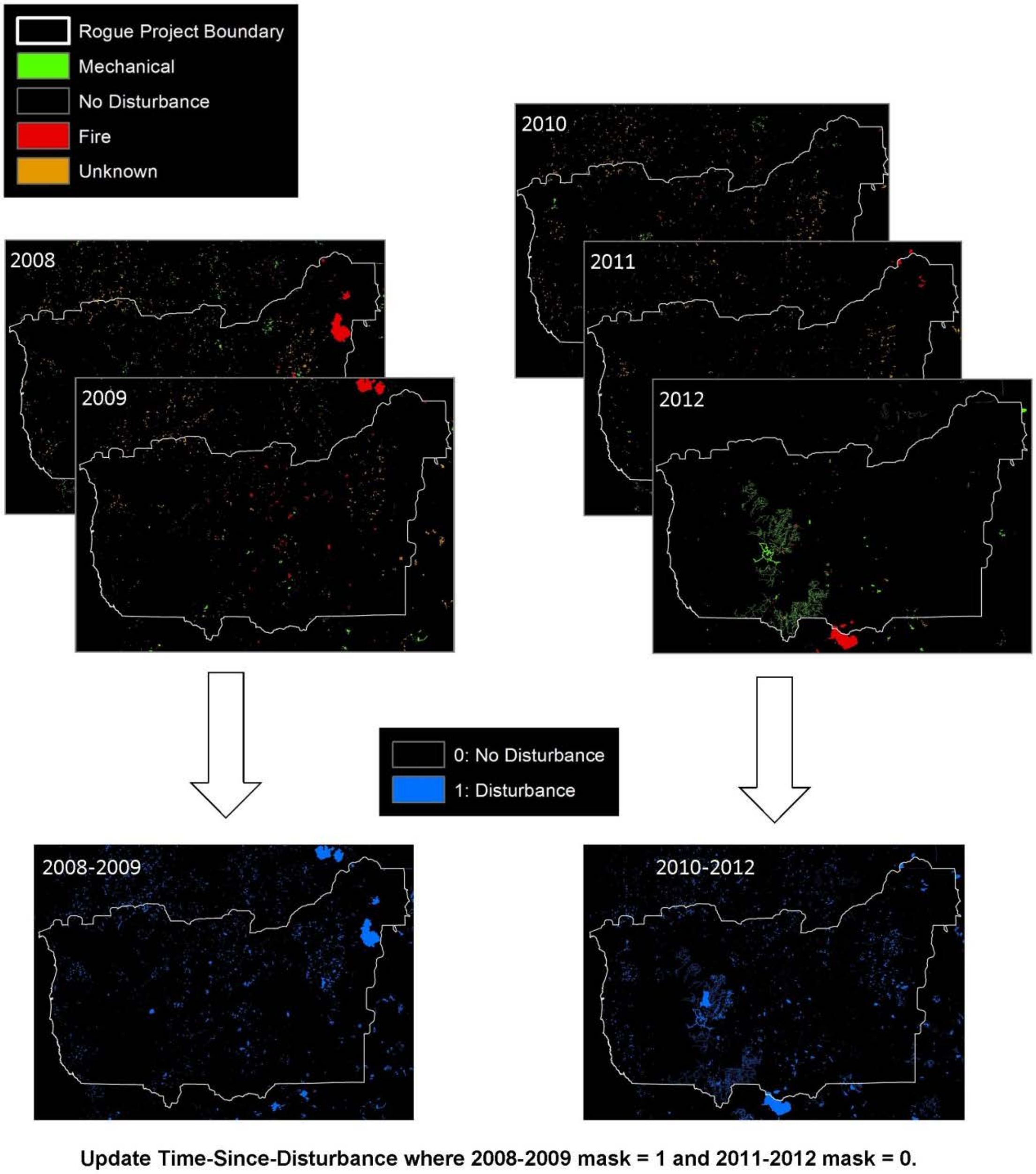


Figure 23. Updating time-since-disturbance. Two geospatial masks were created from the LANDFIRE individual year disturbance layers: one representing disturbances from 2008-2009 and the other representing disturbances from 2010-2012. Time-since-disturbance was updated from the 2-5 year class to the 5-10 year class only where disturbances occurred in 2008-2009 without subsequent disturbance in 2010-2012

With the time-since-disturbance updates complete, we next needed to incorporate 2013 and 2014 disturbances into our updated composite fuel disturbance layer. To reflect large wildfires (> 1,000 acres), we acquired wildfire severity data from the Forest Service Rapid Assessment of Vegetation Condition after Wildfire (RAVG) program website. Recall from Chapter 3 that the LANDFIRE disturbance severity classes represent the effect of disturbances on the vegetation cover of the dominant lifeform. The RAVG program produces a raster data layer representing canopy cover reduction, as a result of fire, through a process that correlates percent change in canopy cover to a remote sensing change detection protocol (Miller and Thode 2007, Miller et al. 2009). We used this data layer to further update the composite fuel disturbance layer based on the percent canopy cover reduction using the ArcGIS Spatial Analyst Extension *Reclassify* tool (Figure 24).

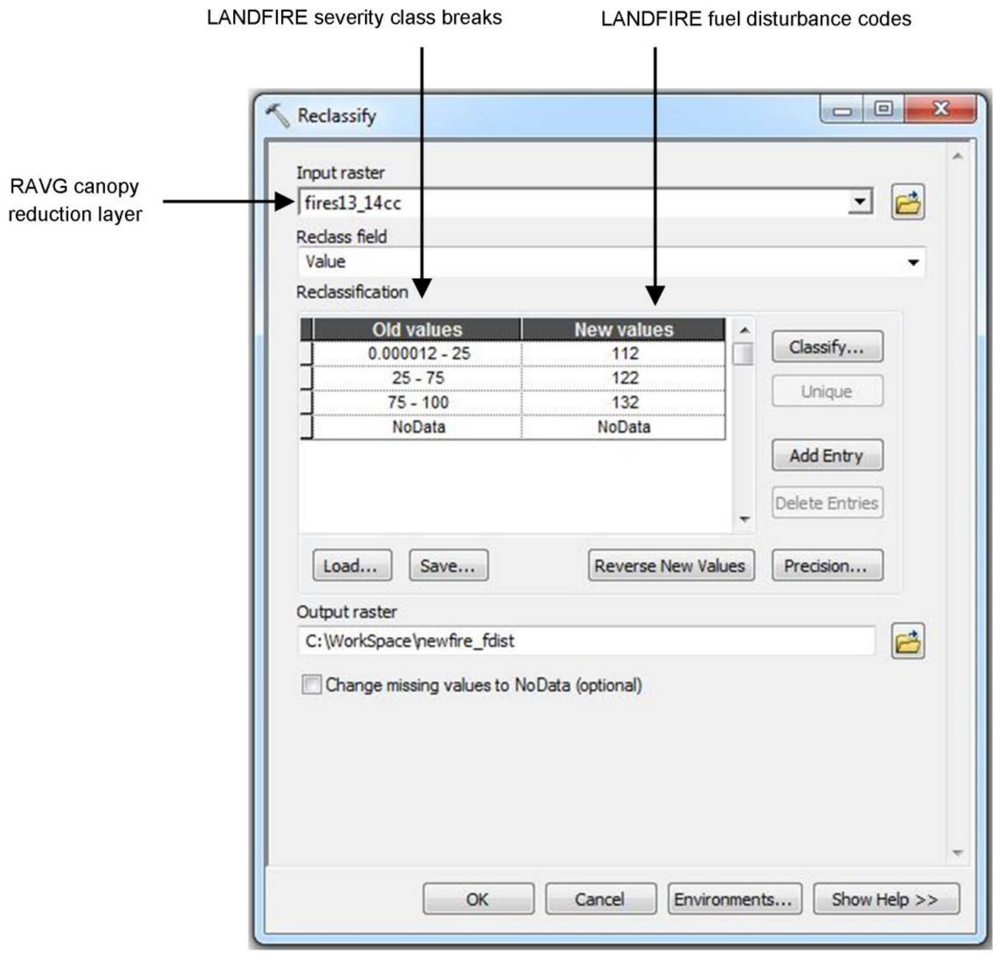


Figure 24. Reclassification of canopy cover reduction estimates from the Rapid Assessment of Vegetation of Condition after Fire (RAVG) program data to LANDFIRE fuel disturbance codes.

We followed a similar process for non-wildfire disturbances. First we acquired 2013 and 2014 Forest Service activities data from the agency's Forest Activities Tracking System (FACTS) and Bureau of Land Management activities from the National Fire Plan Operations and Reporting System (NFPORS). Forest Service and Bureau of Land Management personnel assigned the LANDFIRE disturbance type (mechanical add, mechanical remove, or prescribed fire), severity, and time-since-disturbance codes to each of the activity polygons. If subsequent activities occurred in the two-year time frame, the cumulative effect of those activities was used to determine the most appropriate disturbance attributes. We converted the polygon data to raster format and used ArcGIS Spatial Analyst Extension tools to further update the composite fuel disturbance layer.

Map Unit Accuracy

As mentioned above, our data critique identified two map unit accuracy issues in the disturbance data layer: 1) disturbance type map unit assignments were inaccurate due to generalization of treatment types at the national scale and/or incorrect accounting of cumulative treatment effects, and 2) the grouping of mastication treatments with other mechanical add disturbances does not represent the unique fire behavior of masticated fuel.

We used the ArcGIS Spatial Analyst *combine* function to combine the composite fuel disturbance layer with the individual disturbance layers from 2003-2012. The combine function creates a new raster where each unique combination of values from the input layers represents a single row in the attribute table. Using this table we were able to identify four unique situations and make adjustments based on local resource specialist input (Table 10).

Table 10: Adjustments made to mechanical disturbance type based on local input.

Criteria	Acres	Adjustment
Silvicultural treatments only	200,039	Disturbance type was changed from mechanical remove to mechanical add.
Mastication treatments only	9,188	Created a mask of mastication only pixels and changed the final fuel model values to a "post-mastication" fuel model within the mask during post-processing.
'Other mechanical' treatments only	75,936	Modified disturbance type only if local resource specialists felt the cumulative effect of the treatments was incorrectly assigned.
Combination of mechanical treatment types	289,248	Typically a combination of "other mechanical" and silvicultural treatment. Modified disturbance type only if local resource specialists felt the cumulative effect of the treatments was incorrectly assigned.

Biophysical Setting

Since the biophysical setting data layer represents potential vegetation based on the biophysical characteristics and historical disturbance regime of the site (Chapter 4), disturbances by definition do not have an effect on this layer[2]. Furthermore, because biophysical setting criteria are infrequently used in the LANDFIRE fuel mapping rules for the Northwest Geographic Area, we did not critique this layer for content accuracy.

Existing Vegetation Type

As mentioned above, our data critique identified that oak woodland ecological systems were underrepresented in the existing vegetation type layer. We therefore acquired ancillary geospatial vegetation data developed by the Landscape Ecology, Modeling, Mapping, and Analysis team (LEMMA). We extracted the oak woodland vegetation cover types from this data and augmented the LANDFIRE existing vegetation type data layer using ArcGIS Spatial Analyst tools.

Disturbances may result in a change to the existing vegetation type. For example, tree- or shrub-dominated vegetation may transition to herbaceous-dominated vegetation as a result of high-severity fire. If the existing vegetation type layer was to be used for purposes beyond the critique and development of fuel data, a separate data layer would need to be created to account for any post-disturbance effects to the existing vegetation type. However, since we were only concerned with post-disturbance effects on fuels, we were able to omit this step and rely on our updates to canopy structure and the *canopy guide* feature of the LANDFIRE Total Fuels Change Tool (see below) to correctly assign post-disturbance fuel attributes.

Existing Vegetation Cover

Two updates to the existing vegetation cover layer were required based on our data critique. First, because we used the LEMMA cover type data to augment our existing vegetation type data layer for oak woodland, we also updated the existing vegetation cover layer with LEMMA canopy cover values to ensure consistency across layers. That is, wherever existing vegetation type was updated with LEMMA data, we also updated existing vegetation cover with LEMMA data. Second, we needed to update existing vegetation cover to reflect the 2013 and 2014 disturbances added to the composite fuel disturbance layer.

The structural characteristics of existing vegetation are what the fire behavior fuel model mapping rules are keyed to (Figure 14). We were therefore required to adjust the existing vegetation cover for the new (i.e., 2013 and 2014) disturbances we added to the composite fuel disturbance layer. The post-disturbance canopy cover of forested vegetation types is also required for calculating post-disturbance canopy base height and canopy bulk density.

For the 2013 and 2014 large wildfire disturbances we used the RAVG canopy cover reduction data layer directly to adjust existing vegetation cover. For the non-wildfire disturbances we first assigned a canopy cover reduction value to each severity class midpoint (low severity: 12.5%, moderate severity: 50%, high severity: 87.5%). We did not allow values to be reduced below the lowest canopy cover class (10%-20%) because with few exceptions (e.g., clearcuts), even high-severity disturbances leave some cover. In the case of forested vegetation, leaving 15% forest canopy cover allows for simulating a slight effect of shading and wind reduction to surface fuel from the standing dead trees.

Existing Vegetation Height

[2] Although there are exceptions that could lead to a biophysical setting type conversion, such as those influenced by climate change, uncharacteristic disturbances, and/or exotic species, these occurrences are rare and even if present would have little effect on the assignment of fuel model in this analysis area—that is, biophysical setting criteria are infrequently used in the LANDFIRE fuel model mapping rules in the western states.

As with existing vegetation cover we first updated the existing vegetation height with the LEMMA data in the oak woodland vegetation type.

LANDFIRE existing vegetation height represents the basal-area weighted average of the dominant and co-dominant trees (Chapter 4). In forested vegetation types it is therefore typically not necessary to reduce forest canopy height due to disturbance, as most disturbances would not change the average height significantly enough to reduce existing vegetation height to a lower height class (Table 7). Certain silvicultural methods that target dominant trees, such as clearcuts or thinning from above, are exceptions. For high-severity wildfire, we retained the pre-disturbance canopy height. In combination with the low canopy cover value we assigned, retaining a canopy height value would allow us to simulate a slight effect of the standing dead trees on shading and wind reduction to surface fuel. We were able to prohibit crown fire from being predicted in the post high-severity fire pixels through use of the LANDFIRE Total Fuel Change Tool "canopy guide" function (see below).

Integration of steps with the LANDFIRE Total Fuel Change Tool

With the preliminary critique and updates to the required vegetation and disturbance data layers complete, we then critiqued the LANDFIRE fuel mapping rules using the LANDFIRE Total Fuel Change Tool. A user's guide, tutorial, and information on training for this tool are available on the Wildland Fire Management Research Development and Application – Fuels and Fire Ecology Program website. In this section we will highlight key features of the tool that were used to critique and update fuels for the Rogue Basin analysis.

The LANDFIRE Total Fuel Change Tool provides users the ability to critique and modify the LANDFIRE fire behavior fuel model mapping rules. Additionally, the tool will create canopy fuel data layers (canopy base height and canopy bulk density) using LANDFIRE's methodology, or allow users to "hardcode" base height and bulk density values to unique combinations of vegetation and disturbance attributes. This allows the user to "fine-tune" the interaction of fuel model, canopy base height, and canopy bulk density that is so critical to accurately simulating wildfire behavior.

Critique and Modification of Fire Behavior Fuel Model

The fuel critique was done in a workshop setting where local fire and vegetation specialists from the Forest Service, Bureau of Land Management, and The Nature Conservancy participated. This collaborative approach not only provides a wide range of local knowledge and expertise but also facilitates a sense of ownership and confidence in the end product.

We critiqued the fire behavior fuel model mapping rules for each of the major existing vegetation types in the analysis area. For each existing vegetation type, we first reviewed its description and where it was mapped. If photos were available they would be displayed to provide further context. Next, we discussed which factors—canopy cover; canopy height (a surrogate for stand age); biophysical setting; and disturbance type, severity, and time-since-occurrence—influenced the surface fuels and reviewed how the mapping rules used different combinations of these variables.

Adjustments to the fuel model mapping rules can be made in one of two ways, either to the fuel model assignment itself or to the combination of variables that define a rule (Figure 25). Adjustments to the fuel model assignment were made if workshop participants felt the specified fuel model didn't represent the expected surface fire behavior for the vegetation type and structure identified (that is, if the flame length was too high/low or the rate of spread was too fast/slow). The LFTFC tool provides an interface for comparing the flame length and rate of spread of different fuel models under varying combinations of fuel moisture, slope, and wind speed (Figure 26) as an aid to making modification decisions. Adjustments to the canopy cover and height thresholds, or addition of biophysical setting criteria will influence the spatial distribution and proportion of area assigned to each fuel model. We modified these criteria if participants felt the location or distribution of fuel models did not reflect on-the-ground conditions.

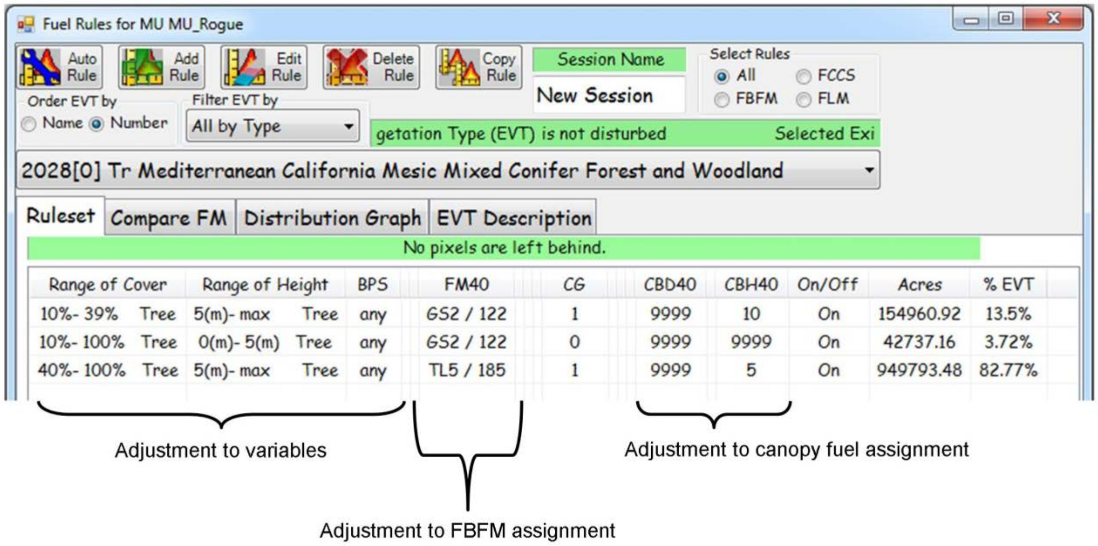


Figure 25. LANDFIRE Total Fuel Change Tool rulesets. Adjustments can be made to the range of variables, fire behavior fuel model (FBFM), and canopy fuel.

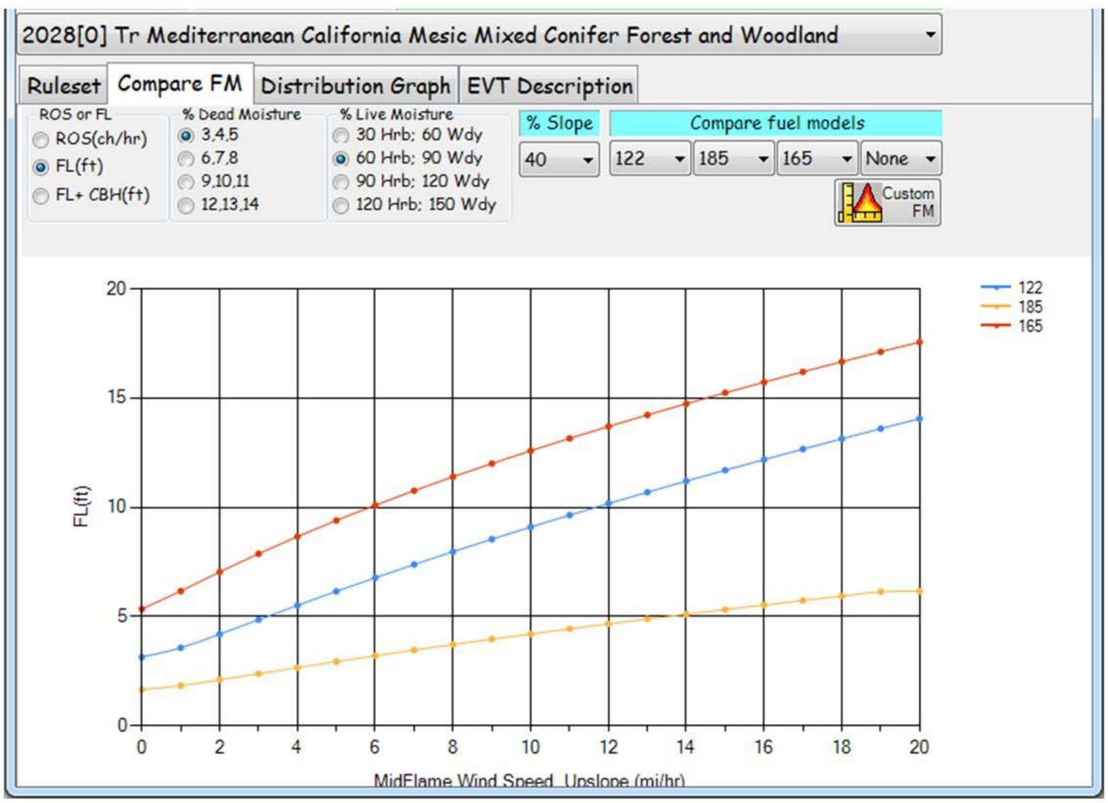


Figure 26. Comparing fuel models. The LANDFIRE Total Fuel Change Tool has built-in functionality to compare fire behavior between fuel models under a variety of fuel moisture and slope conditions.

Finally, for areas where a mastication treatment occurred we assigned the fire behavior fuel model outside of the LANDFIRE Total Fuel Change Tool using ArcGIS Spatial Analyst tools.

Critique and Modification of Canopy Fuels

There are two ways a user has control over how canopy fuels are mapped with the LANDFIRE Total Fuel Change Tool. The first is to use the tool's canopy guide feature; the second is to "hardcode" canopy fuel values. The canopy guide options are as follows:

- 0: No forest canopy structure characteristics (i.e., cover and height) or fuels are assigned. In forested existing vegetation types this may be used to represent a disturbance that removes the forested canopy (e.g., clearcut) or when the "forested" canopy is already considered in the fire behavior fuel model assignment (e.g., short trees).
- 1: The standard LANDFIRE methodologies (Chapter 5) are used to calculate canopy structure and canopy fuel values.
- 2: The canopy base height and canopy bulk density are artificially set to a point where crown fire—passive, active, or conditional (Scott and Reinhardt 2001)—will not be simulated (canopy base height of 10m and canopy bulk density of 0.012 kg/m-3). This value may be used in cases where canopy height and canopy cover values are still desired due to their influence on reducing wind speed and dead fuel moisture content through shading (Chapter 5) but where crown fire is unlikely (e.g., broadleaf forests).

We set the canopy guide value to 2 for all high-severity fire disturbances. As discussed previously, this technique allows for the standing dead trees to still have some, albeit minimal, influence on dead fuel moisture content and wind reduction, but eliminates crown fire and spotting from being modeled in fire behavior modeling systems. The use of a canopy guide value of 2 also served as an alternative to modifying the existing vegetation type due to high-severity fire. That is, by "turning off" crown fire and assigning the appropriate fire behavior fuel model for the expected change in the dominant vegetative lifeform, we accomplished the same goal.

For non-disturbed, and low- and moderate-severity fire disturbances, we assessed the effect of fire behavior fuel model and the LANDFIRE default canopy base height values on crown-fire initiation using the NEXUS (Scott 1999) fire modeling system (Figure 27). Canopy base height values were "hardcoded" (Figure 25) in the fuel rules if workshop participants felt that simulated crown-fire initiation didn't accurately represent expected crown-fire initiation. There are many factors to consider when assigning a canopy base height value. Knowledge of local wind patterns and/or analysis of the wind data that will be used in your analysis are paramount. We accepted the LANDFIRE default canopy base height assignments for all mechanical disturbances.

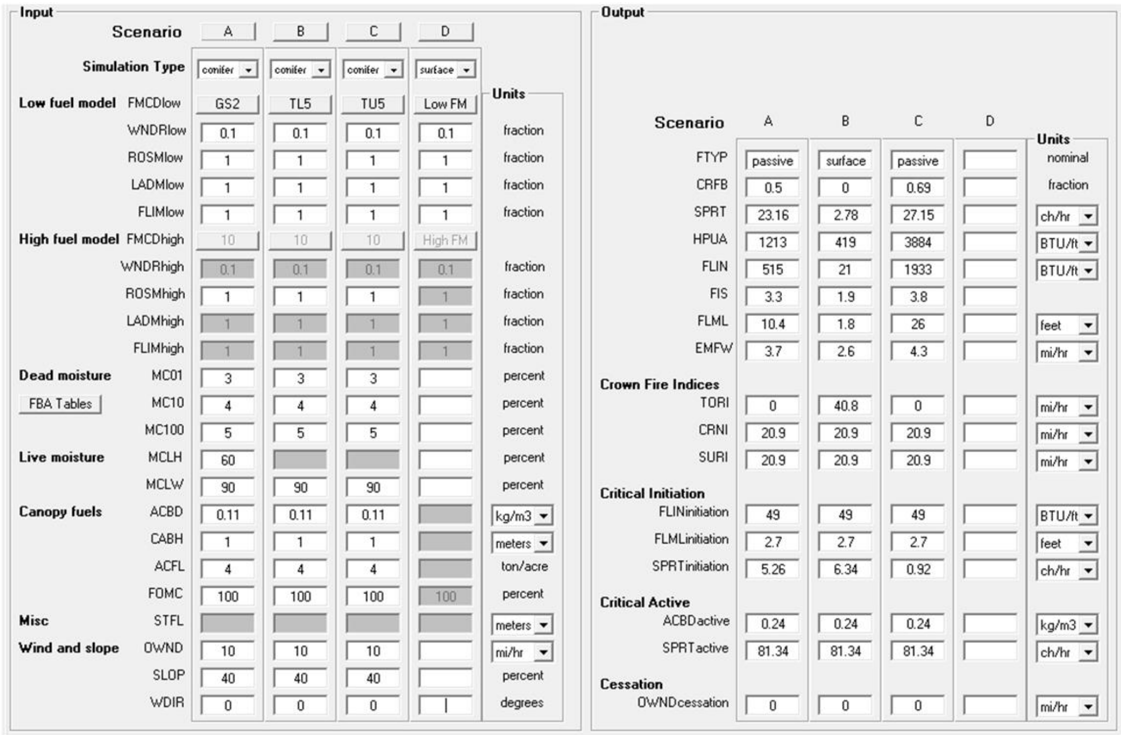


Figure 27. NEXUS fire modeling system. NEXUS facilitates in depth fire behavior critique and is particularly useful in assessing the environment conditions required to transition surface fire to crown fire based on fire behavior fuel model and canopy base height values.

Analysis

We created a new fire behavior modeling landscape (i.e., LCP file) based on our updated disturbance data layers and fuel model mapping rules. We then used this LCP to run basic fire behavior simulations as an additional critique. This final analysis step was used to highlight issues that were possibly overlooked or might have been hard to detect during the fuel calibration, thus necessitating further data modifications. After completion of this final step, the modified fuel data layers were used to analyze wildfire hazard in the Rogue Basin.

Example 2: Using LANDFIRE for local vegetation departure analysis

In this example we illustrate the data critique and update tasks conducted as part of an analysis of vegetation departure in the southern Sierra Nevada Mountains. The 12.5 million-acre planning area includes the Inyo, Sequoia, and Sierra National Forests; Sequoia and Kings Canyon National Parks; and portions of Yosemite and Death Valley National Parks (Figure 21). Because LANDFIRE provides wall-to-wall geospatial vegetation data, it was an obvious choice for vegetation departure analysis at such a broad spatial extent.

Define objectives

The objective of this project was to conduct a vegetation departure analysis using the FRCC Mapping Tool (Hutter et al. 2012) and LANDFIRE data. The results of this analysis would be further integrated into a wildfire hazard and risk assessment. The analysis was conducted in the fall of 2013.

Identify data requirements

Vegetation departure analysis requires data that characterize both the historical and current vegetation condition. LANDFIRE vegetation dynamics models (Chapter 6) would be used to describe the baseline historical conditions for each biophysical setting mapped to the analysis extent. LANDFIRE vegetation data would be used to characterize the current vegetation composition and structure. LANDFIRE 2008 vegetation data layers were acquired and updated for disturbance through 2012 by USDA Forest Service regional office geospatial analysts.

Critique and modification

We began our critique by listing biophysical settings by analysis area acreage from largest to smallest. A team of regional ecologists, vegetation specialists, and GIS and remote sensing specialists reviewed the data list to determine which biophysical settings to assess for departure. Biophysical setting classes comprising insignificant acreage, those that were difficult to accurately map (Chapter 6), and those determined not important to the analysis objectives were dropped. The review team further determined that the thematic resolution (Chapter 1) of the biophysical setting data layer was too fine, given local knowledge of historical vegetation dynamics and disturbance regimes (Chapter 6). Biophysical setting classes were therefore grouped (Table 11) based on recently developed presettlement fire regime groups that summarize presettlement fire frequency estimates for California ecosystems dominated by woody plants (Van de Water and Safford 2011).

Because the analysis area intersects multiple LANDFIRE map zones, we next reviewed the vegetation dynamics models for each of the biophysical settings for consistency across zones. It is common for the vegetation dynamics model to differ across zones for the same biophysical setting. If the map zone boundary reflects an ecological transition, then the differences between models may be appropriate (Chapter 6). However, if the map zone boundary creates an artificial demarcation in the analysis area, users will want to choose a single model that best fits the analysis area. The review team chose the most representative vegetation dynamics model for each biophysical setting or group of biophysical settings to be assessed. The LANDFIRE 2008 biophysical setting data layer was reclassified using the *reclassify* tool in the ArcGIS Spatial Analyst extension to the final 15 classes represented in Table 11.

Table 11: LANDFIRE biophysical setting (BpS) model groupings for the Southern Sierra vegetation departure analysis.

LANDFIRE Biophysical Setting Name	LANDFIRE BpS Code	Presettlement Fire Regime[a]	LANDFIRE Model Used in VCA[b]
Inter-Mountain Basins Big Sagebrush Shrubland	10800	Big Sagebrush	610800
Inter-Mountain Basins Big Sagebrush Steppe	11250		611260
Inter-Mountain Basins Montane Sagebrush Steppe	11260		
Great Basin Xeric Mixed Sagebrush Shrubland	10790	Black and Low Sagebrush	610790
California Mesic Chaparral	10970	Chaparral-Serotinous Conifers	611050
California Montane Woodland and Chaparral	10980		
Great Basin Semi-Desert Chaparral	11030		
Northern and Central California Dry-Mesic Chaparral	11050		
Sonora-Mojave Semi-Desert Chaparral	11080		
Mediterranean California Dry-Mesic Mixed Conifer Forest and Woodland	10270	Dry Mixed Conifer	610270
Sierra Nevada Subalpine Lodgepole Pine Forest and Woodland	10580	Lodgepole Pine	610581
Sierra Nevada Subalpine Lodgepole Pine Forest and Woodland - Wet	10581		
Mediterranean California Mesic Mixed Conifer Forest and Woodland	10280	Moist Mixed Conifer	610280
California Lower Montane Blue Oak-Foothill Pine Woodland and Savanna	11140	Oak Woodland	611140
Mediterranean California Mixed Oak Woodland[c]	10290	Mixed Evergreen	410140
Great Basin Pinyon-Juniper Woodland	10190	Pinyon-Juniper	610190
Mediterranean California Red Fir Forest - Cascades	10321	Red Fir	610321
Mediterranean California Red Fir Forest - Southern Sierra	10322		610322
Mediterranean California Subalpine Woodland	10330	Subalpine Forest	610330
Northern California Mesic Subalpine Woodland	10440		
Sierra Nevada Subalpine Lodgepole Pine Forest and Woodland - Dry	10582	Lodgepole Pine	
Inter-Mountain Basins Subalpine Limber-Bristlecone Pine Woodland	10200	Subalpine Forest	610200
Rocky Mountain Subalpine-Montane Limber-Bristlecone Pine Woodland	10570		
California Montane Jeffrey Pine(-Ponderosa Pine) Woodland	10310	Yellow Pine	610310
Mediterranean California Lower Montane Black Oak-Conifer Forest and Woodland	10300		

[a] Van de Water and Safford (2011) pre-settlement fire regime vegetation types shown for reference.
[b] Vegetation Condition Assessment.
[c] Based on local knowledge and ancillary vegetation data, workshop participants felt that areas mapped as a Mediterranean California Mixed Oak Woodland biophysical setting were incorrectly classified and should be classified as Central and Southern California Mixed Evergreen Woodland (BpS model 410140).

Next, the succession class mapping rules for each of the final vegetation dynamics models were assessed. Adjustments were made to ensure rules were *exhaustive* and *mutually exclusive*, and that uncharacteristic native conditions were appropriately represented for the local area (Chapter 6). Succession class was then remapped, accounting for the adjustments, using ArcGIS software (Figure 28). First, the existing vegetation type layer was reclassified to create an exotic vegetation mask, where exotic vegetation types were assigned a value of 1 and native vegetation types were assigned a value of 0. Next, the biophysical setting, existing vegetation cover, existing vegetation height, and exotic vegetation mask data layers were combined using the ArcGIS Spatial Analyst extension *combine* tool. A new field was then added to the output combine layer and populated with the new succession class values by first selecting combinations of the data layer attributes as defined in the mapping rules and using the *field calculator* function. Finally, after all combinations had been assigned a new succession class value, the ArcGIS Spatial Analyst extension *lookup* tool was used to create a new succession class data layer.

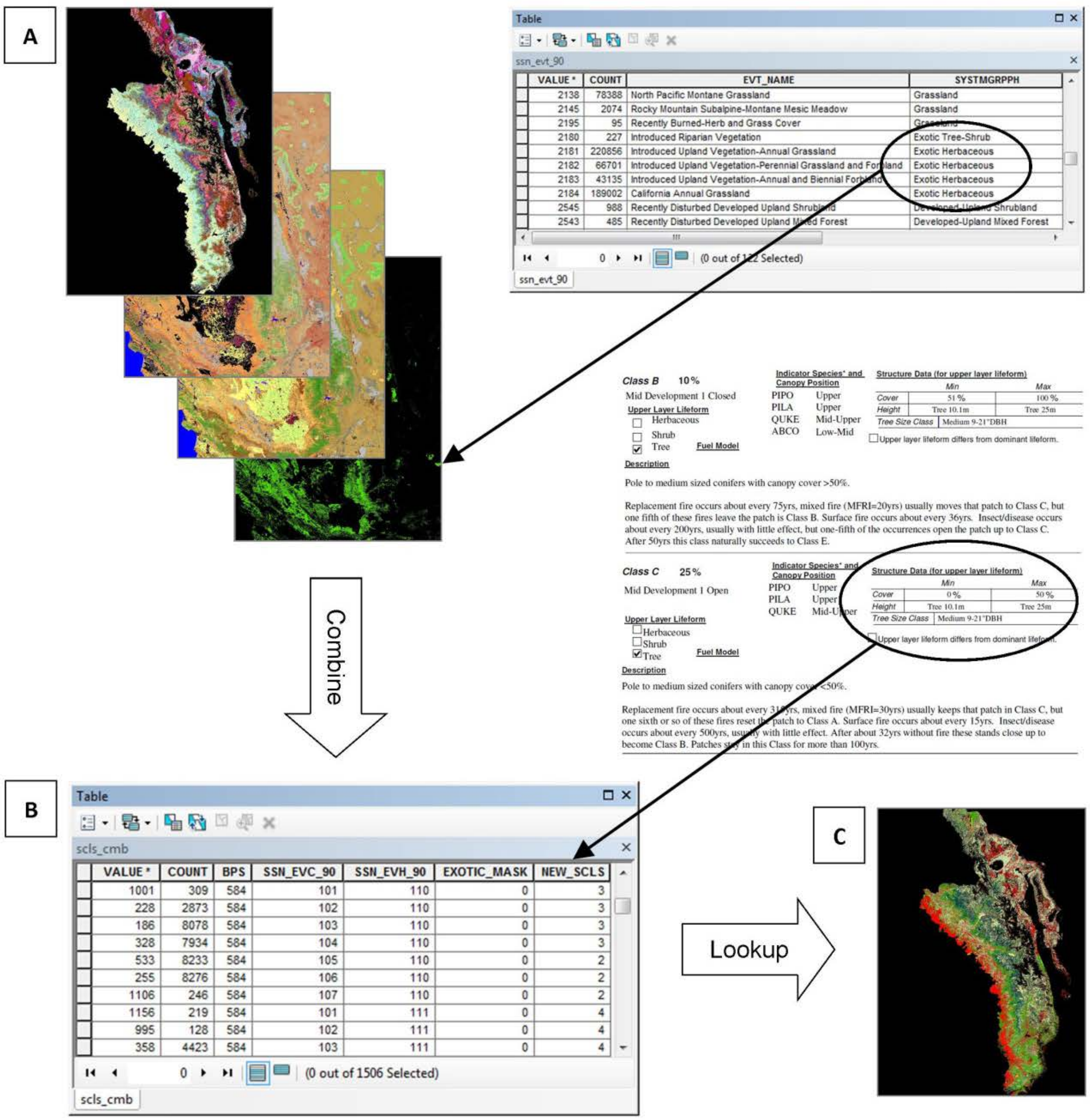


Figure 28. Succession class remapping process. (A) Biophysical setting, existing vegetation cover and height, and exotic vegetation data layers were combined using ArcGIS Spatial Analyst. (B) New succession class values were then assigned based on vegetation dynamics models and adjustments defined by local specialists. (C) Finally, the ArcGIS Spatial Analyst *lookup* tool was used to create a new succession class spatial data layer.

Analysis

We created a spatial landscape assessment unit data layer for conducting the vegetation departure analysis. Each biophysical setting was assigned to an assessment unit based on fire regime characteristics, including historical fire-size distribution (Barrett et al. 2010). Finally, we ran the Fire Regime Condition Class Mapping Tool and reviewed the results.

No issues were identified and the results informed managers where on the landscape specific vegetation development classes (i.e., succession class) were in either surplus or deficit in relation to their presettlement condition. As noted in Example 1 of this chapter, sometimes an analysis may highlight issues that were overlooked or hard to detect earlier in the data critique process that necessitate further data modifications. Analysis should be viewed as an iterative process.

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REFERENCES

Anderson, H.E. 1982. Aids to determining fuel models for estimating fire behavior. General Technical Report INT-122. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 22 p.

Andrews, P.L. 2013. Current status and future needs for the BehavePlus fire modeling system. Int J Wildland Fire 23(1): 21-33.

Aycrigg J.L. Davidson, A. Svancra, L.K. Gergely, K.J. et al. 2013**.** Representation of ecological systems within the protected areas network of the continental United States. PLoS ONE 8(1): e54689. 2013 Jan 23.

Barrett, S. Havlina, D. Jones, J. et al. 2010. Interagency Fire Regime Condition Class Guidebook. Version 3.0 [Homepage of the Interagency Fire Regime Condition Class website, U.S. Department of Agriculture, Forest Service; U.S. Department of the Interior; and The Nature Conservancy]. Available: https://www.frames.gov/files/7313/8388/1679/ FRCC_ Guidebook_2010_final.pdf

Blankenship, K. Smith, J. Swaty, R. Shlisky, A. Patton, J. and Hagen, S. 2012. Modeling on the grand scale: LANDFIRE lessons learned. In: Kerns, B.K.; Shlisky, A.J. and Daniel, C.J. (tech. eds). Proceedings of the First Landscape State-and-Transition Simulation Modeling Conference; 2011 June 14–16; Portland, OR. Gen. Tech. Rep. PNW-GTR-869. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 43-56.

Cleland, D.T., Freeouf, J.A., Keys, J.E., Nowacki, G. J., Carpenter, C.A. and McNab, W.H. 2005. Ecological subregions: Sections and subsections for the conterminous United States. Presentation scale 1:3,500,000, colored. U.S. Department of Agriculture, Forest Service, Washington, DC.

Cochrane, M.A., Moran, C.J., Wimberly, M.C., Baer, A.D., Finney, M.A., Beckendorf, K.L., Eidenshink, J. and Zhu, Z. 2012. Estimation of wildfire size and risk changes due to fuels treatments. Int J Wildland Fire 21: 357-367. doi: 10.1071/WF11079

Comer, P., Faber-Langendoen, D., Evans, R., Gawler, S., Josse, C., Kittel, G., Menard, S., Pyne, M., Reid, M., Schulz, K., Snow, K. and Teague, J. 2003. Ecological systems of the United States: a working classification of U.S. terrestrial systems. NatureServe, Arlington, VA.

Cruz, M.G.; Alexander, M.E. and Wakimoto, R.H. 2003. Assessing canopy fuel stratum characteristics in crown fire prone fuel types of western North America. Int J Wildland Fire 12: 39-50. doi: 10.1071/WF02024

Dixon, G.E. comp. 2002 [Revised 2014 July 2]. Essential FVS: A user's guide to the forest vegetation simulator. Internal Rep. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Forest Management Service Center. 226 p.

ESSA Technologies Ltd. 2007. Vegetation dynamics development tool user guide, v. 6.0. Prepared by ESSA Technologies Ltd., Vancouver, BC. 196 p.

Finney, M.A. 2006. An overview of FlamMap fire modeling capabilities. In: Fuels Management **-** How to Measure Success: Conference Proceedings. 2006 March 28-30; Portland, OR. Andrews, P.L. and Butler, B.W. (compilers). U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Fort Collins, CO. Proceedings. RMRS-P-41. 213-220.

Finney, M.A. 1998. FARSITE: Fire Area Simulator—model development and evaluation. Research Paper RMRS-RP-4. Ft. Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 47 p.

Helmbrecht, D., Williamson, M. and Abendroth, D. 2012. Bridger-Teton National Forest vegetation condition assessment. Prepared for Bridger-Teton National Forest. U.S. Department of Agriculture, Forest Service, February 25, 2012. 38 p.

Huang, C., Goward, S.N., Masek, J.G., Thomas, N., Zhu, Z. and Vogelmann, J.E. 2010. An automated approach for reconstructing recent forest disturbance history using dense Landsat time series stacks. Remote Sens. Environ. 114(1): 183-198.

Hutter, L., Jones, J. and Hamilton, D. 2012. Fire Regime Condition Class Mapping Tool (FRCCMT) for ArcGIS 10, v. 3.1.0. National Interagency Fuels, Fire, & Vegetation Technology Transfer. Available: www.frames.gov/frcc

Jennings, S.B., Brown, N.D. and Sheil, D. 1999. Assessing forest canopies and understory illumination: canopy closure, canopy cover and other measures. Forestry 72(1): 59-74.

Jin, S., Yang, L., Danielson, P., Homer, C., Fry, J. and Xian, G. 2013. A comprehensive change detection method for updating the National Land Cover Database to circa 2011. USGS Staff -- Published Research. Paper 711. Available: http://digitalcommons.unl.edu/usgsstaffpub/711

Jones, J. and Ryan, C. 2012. Fire Regime Condition Class Mapping Tool (FRCCMT) User's Guide. National Interagency Fuels, Fire, & Vegetation Technology Transfer. Available: https://www.frames.gov/partner-sites/wfmrda-ffe/home/

Kellendorfer, J., Walker, W., Pierce, L., Dobson, C., Fites, J.A., Hunsaker, C., Vona, J. and Clutter, M. 2004. Vegetation height estimation from shuttle radar topography mission and national elevation datasets. Remote Sens. Environ. 93: 339-358.

Key, C.H. and Benson, N.C. 2005. Landscape assessment: remote sensing of severity, the normalized burn ratio and ground measure of severity, the composite burn index. In: FIREMON: fire effects monitoring and inventory system. General Technical Report RMRS-GTR-164-CD: LA1-LA51. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden, UT, USA.

[LFDAT] LANDFIRE Data Access Tool for ArcGIS 10 (v. 2.4). 2012. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station and National Interagency Fuels Technology Transfer. Available: http://www.landfire.gov/download_lfdat.php

[LFRDB] LANDFIRE Reference Database. n.d. [cited 2014 Non 8]. LANDFIRE Program, U.S. Department of Agriculture, Forest Service; U.S. Department of Interior. Available: http://www.landfire.gov/index.php

[LFTFCT] LANDFIRE Total Fuel Change Tool (ToFu Δ) for ArcGIS 10 (v. 0.12). 2011. National Interagency Fuels Technology Transfer; U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station; LANDFIRE Fuels Development Team, SGT, Inc.; and U.S. Geological Survey. Available: http://www.landfire.gov/download_lfdat.php

Miller, J. D. and Thode, A. E. 2007. Quantifying burn severity in a heterogeneous landscape with a relative version of the delta Normalized Burn Ratio (dNBR). Remote Sens. Environ. 109(1): 66-80.

Miller, J.D., Knapp, E.E., Key, C.H., Skinner, C.N., Isbell, C.J., Creasy, R.M. and Sherlock, J.W. 2009. Calibration and validation of the relative differenced Normalized Burn Ratio (RdNBR) to three measures of fire severity in the Sierra Nevada and Klamath Mountains, California, USA. Remote Sens. Environ. 113(3): 645-656.

Nelson, K.J., Connot, J., Peterson, B. and Martin, C. 2013. The LANDFIRE refresh strategy: updating the national dataset. Fire Ecol. 9(2): 80-101.

Noonan-Wright, E.; Opperman, T.S.; Finney, M.A.; Zimmerman, G.T.; Seli, R.C.; Elenz, L.M.; Calkin, D.E. and Fiedler, J.R. 2011. Developing the U.S. Wildland Fire Decision Support System. J. Combustion. 2011: Article ID 168473. 14 p.

Price, J., Silbernagel, J., Miller, N., Swaty, R., White, M. and Nixon, K. 2012. Eliciting expert knowledge to inform landscape modeling of conservation scenarios**.** Ecol. Model. 229(2012): 76-87.

Provencher, L., Blankenship, K., Smith, J., Campbell, J. and Polly, M. 2009. Comparing locally derived and LANDFIRE geo-layers in the Great Basin, USA. Fire Ecol. 5(2): 126-132.

Reeves, M.C. and Mitchell, J.E. 2011. Extent of coterminous US rangelands: quantifying implications of differing agency perspectives. Rangel. Ecol. Manag. 64: 585-597. doi: 10.2111/REM-D-11-00035.1.

Reeves, M.C., Ryan, K.C., Rollins, M.G. and Thompson, T.G. 2009. Spatial fuel data products of the LANDFIRE project. Int. J. Wildland Fire 18(3): 250-267.

Reinhardt, E. and Crookston, N.L. (tech. eds). 2003. The Fire and Fuels Extension to the Forest Vegetation Simulator. General Technical Report RMRS-GTR-116. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 209 p. Available: http://www.fs.fed.us/rm/pubs/rmrs_gtr116.html

Riano, D., Chuvieco, E., Salas, J., Palacios-Orueta, A. and Bastarrika, A. 2002. Generation of fuel type maps from Landsat TM images and ancillary data in Mediterranean ecosystems. Can. J. For. Res. 32: 1301–1315. doi: 10.1139/X02-052.

Rollins, M.G. 2009. LANDFIRE: a nationally consistent vegetation, wildland fire, and fuel assessment. Int. J. Wildland Fire 18: 235-249.

Rothermel, R.C. 1972. A mathematical model for predicting fire spread in wildland fuels. Research Paper INT-115. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 40 p.

Sando, R.W. and Wick, C.H. 1972. A method of evaluating crown fuels in forest stands. U.S. Department of Agriculture, Forest Service, Research Paper NC-84.

Scott, J.H. 1999. NEXUS: A system for assessing crown fire hazard. Fire Manag. Notes 59(2): 20-24.

Scott, J.H. and Reinhardt, E.D. 2001. Assessing crown fire potential by linking models of surface and crown fire behavior. Research Paper RMRS-RP-29. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 59 p.

Scott, J.H. and Reinhardt, E.D. 2005. Stereo photo guide for estimating canopy fuel characteristics in conifer stands. General Technical Report RMRS-GTR-145. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 49 p. plus stereoscope.

Scott, J.H. 2012. Introduction to wildfire behavior modeling. National Interagency Fuels, Fire, & Vegetation Technology Transfer. [Online]. Available: https://www.frames.gov/files/8413/4643/5159/Intro_to_Fire_Behavior_Modeling_Guide_2012.06.25.pdf.

Scott et al 2012 Scott, J.H., D.J. Helmbrecht, S.A. Parks, and C. Miller. 2012. Quantifying the threat of unsuppressed wildfires reaching the adjacent wildland-urban interface on the Bridger-Teton National Forest, Wyoming, USA. Fire Ecology 8(2): 125-142. doi: 10.4996/fireecology.0802125.

Scott, J.H. and Burgan, R.E. 2005. Standard fire behavior fuel models: a comprehensive set for use with Rothermel's surface fire spread model. General Technical Report RMRS-GTR-153. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 72 p.srm.

Seaber, P.R., Kapinos, F.P. and Knapp, G.L. 1987. Hydrologic Unit Maps: U.S. Geological Survey Water-Supply Paper 2294, 63 p. Available from http://water.usgs.gov/GIS/huc.html

Stratton, R.D. 2006. Guidance on spatial wildland fire analysis: models, tools, and techniques. General Technical Report RMRS-GTR-183. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 15 p.

Stratton, R.D. 2009. Guidebook on LANDFIRE fuels data acquisition, critique, modification, maintenance, and model calibration. General Technical Report RMRS-GTR-220. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 54 p.

Swaty, R., Blankenship, K., Hagen, S., Fargione, J., Smith, J., et al. 2011. Accounting for ecosystem alteration doubles estimates of conservation risk in the conterminous United States**.** PLoS ONE 6(8): e23002. doi:10.1371/journal.pone.0023002. 2011 Aug 5.

Swetnam, T.W., Allen, C.D. and Betancourt, J.L. 1999. Applied historical ecology: using the past to manage for the future. Ecol. Appl. 9: 1189-1206.

The Nature Conservancy. 2011a. Reviewing and modifying LANDFIRE vegetation dynamics models. The Nature Conservancy, Arlington, VA. Available from https://www.conservationgateway.org/Files/Pages/reviewing-modifying-landf.aspx

The Nature Conservancy. 2011b. Reviewing and modifying LANDFIRE spatial products. The Nature Conservancy, Arlington, VA. Available from https://www.conservationgateway.org/Files/Pages/reviewing-modifying-landfaspx88.aspx

The Nature Conservancy. 2013. How to map successional stages using LANDFIRE products. The Nature Conservancy, Arlington, VA. Available from https://www.conservationgateway.org/Files/Pages/SClassHUG.aspx

Toney, C., Shaw, J.D. and Nelson, M.D. 2009. A stem-map model for predicting tree canopy cover of Forest Inventory and Analysis (FIA) plots. In: McWilliams, W., Moisen, G. and Czaplewski, R. (comps). Proceedings of the 2008 Forest Inventory and Analysis (FIA) symposium. 2008 October 21-23; Park City, UT. Conf. Proc. RMRS-P-56CD. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 19 p.

Toney, C., Peterson, B., Long, D., Parsons, R. and Cohn, G. 2012. Development and applications of the LANDFIRE forest structure layers. In: Morin, R.S. and Liknes, G.C. (comps). Moving from Status to Trends: Forest Inventory and Analysis (FIA) Symposium. 2012 December 4-6; Baltimore, MD. General Technical Report NRS-P-105. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 305-309.

Tuhy, J., Provencher, L. and Low, G. 2010. Landscape conservation forecasting: report to the Powell Ranger District, Dixie National Forest**.** September 2010. 136 p. Available from https://www.conservationgateway.org/Files/Pages/landscape-conservation-foaspx55.aspx

Turner, M.G., Gardner, R.H., and O'Neill, R.V. 2001. The critical concept of scale. In: Landscape Ecology in Theory and Practice: Pattern and Process. New York: Springer. 25-45.

[USDAFS] USDA Forest Service. 2009 [cited 2015 July 24]. Reference guide FSPro overview. In Wildland Fire Decision Support System. Available: http://wfdss.usgs.gov/wfdss/pdfs/fspro_reference.pdf

USFS. (n.d.). Fire Regime Data products formerly referred to as FRCC and FRCC Departure Index are now called Vegetation Condition Class (VCC) and Vegetation Departure (VDEP) [Data notification]. In LANDFIRE Program. Retrieved June 1, 2015, from http://www.landfire.gov/notifications16.php

USFS. (n.d.). Forest Canopy Cover Appears High: External review has suggested that LANDFIRE forest canopy cover estimates are too high [Data notification]. In LANDFIRE Program. Retrieved June 1, 2015, from http://www.landfire.gov/notifications16.php

USFS. (2013, February 19). LANDFIRE Public Events Data Dictionary. In LANDFIRE Program. Retrieved from http://www.landfire.gov/downloadfile.php?file=LANDFIREPublicEventsDataDictionary.pdf

USFS. (2015, July 15). Scale & Use of LANDFIRE Products. In LANDFIRE Program. Retrieved from http://www.landfire.gov/downloadfile.php?file=Scale_and_Use_of_LF_Data.pdf

USGS. (2010, January 01). Wildland Fire Science, Earth Resources Observation and Science Center, U.S. Geological Survey. LANDFIRE Canopy Base Height [Metadata]. In LANDFIRE.US_130CBH. Retrieved March 31, 2013, from http://landfire.cr.usgs.gov/distmeta/servlet/gov.usgs.edc.MetaBuilder?TYPE=HTML&DATASET=F0C

Van de Water, K.M. and Safford, H.D. 2011. A summary of fire frequency estimates for California vegetation before Euro-American settlement. Fire Ecol. 7(3): 26-58. doi: 10.4996/fireecology.0703026

Zhu, Z., Bergmaschi, B., Bernknopf, R., Clow, D., Dye, D., Faulkner, S., Forney, W., et al. 2010. A method for assessing carbon stocks, carbon sequestration, and greenhouse-gas fluxes in ecosystems of the United States under present conditions and future scenarios. U.S. Geological Survey, Scientific Investigations Report 2010-5233, Reston, VA, USA.