# Developing the LANDFIRE Fire Regime Data Products

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## OVERVIEW

Developing nationally consistent data products describing ecological departure from historical conditions and historical fire regimes is a main component of the LANDFIRE Project. The purpose of this document is to describe the development of LANDFIRE data products related to characterizing historical vegetation conditions and fire regimes, these include: 1) maps of potential vegetation (an important pre-cursor to LANDFIRE fire regime products); models of vegetation dynamics, maps characterizing current seral status (succession class), maps of fire regime groups (FRG), and maps of fire regime condition class (FRCC) and FRCC departure. Potential vegetation and succession class maps are developed using gradient modeling and remote sensing methodologies; vegetation dynamics models are created at regional workshops organized by The Nature Conservancy; FRG maps are developed by combining maps of simulated mean fire return interval and percent replacement-severity fire (http://www.frcc.gov, NIFC 2007); and FRCC and FRCC departure maps are developed using the methods described in the interagency FRCC guidebook (http://www.frcc.gov). All LANDFIRE data products are available at http://www.landfire.gov.

## LANDFIRE SCOPE AND APPLICATIONS

The LANDFIRE Project charter states: “LANDFIRE is a landscape-scale fire, ecosystem, and fuel assessment mapping project designed to generate comprehensive maps of vegetation, fire and fuel characteristics nationally and identify and develop a set of tools to create and distribute data to users.” This statement must always frame any discussion about the data products developed by LANDFIRE. Within this context, the summary and reporting of LANDFIRE fire regime data products nationally should include reporting by state and entire bureau/agency ownership. Any characterization or use of the data below that level is the responsibility of the user. Several analysis tools for working with

LANDFIRE data products at finer spatial scales have been developed by the National Interagency Fuel Technology Team and are provided as part of the LANDFIRE deliverables (see http://frames.nbii.gov/niftt/).

Inherent limitations of LANDFIRE fire regime data products include but are not limited to:

1) Based on the Interagency FRCC methodology, LANDFIRE established break points to simplify and clarify data display. In other words, FRCC is mapped in three distinct categories rather than continuously
2) LANDFIRE was not chartered to collect new field data. Data product development and the verification of products were based on existing field-referenced databases that were collected for numerous purposes and are not nationally consistent in quality or quantity. To help mitigate this, LANDFIRE developed methods for compiling these disparate databases into a single, consistent format for use in product development and verification (Caratti 2006).
3) The Landsat imagery used in the data characterization process is several years old (much is from calendar year 2000 and earlier). As a result, recent disturbance and management activities are not represented nor are changes in ecosystems with relatively rapid vegetation succession cycles. Bringing the data up to currency is a main component of LANDFIRE Operations and Maintenance.
4) Edge effects between LANDFIRE mapzones are present due to independent mapzone development and limited time available to resolve edge effect issues given the project scope, budget, and schedule.

Summarization at the national and state levels does not change the relevance of LANDFIRE data products available to support management decisions at the unit level. The advantages of a nationally consistent seamless data set and repeatable methodology mitigate any short comings of the LANDFIRE data products when used at the local level. Much of the information included above is

derived from an Interagency Fuel Coordination Group memorandum dated April 12, 2007, available at http://www.landfire.gov.

## LANDFIRE METHODOLOGY

Fire regime condition class maps are developed by comparing historical reference conditions of vegetation composition and structure -- simulated using the landscape succession model LANDSUM -- with existing vegetation composition and structure (termed *current conditions* in Hann and others 2004) developed using field-referenced data and Landsat imagery (Holsinger and others 2006a; Pratt and others 2006; Keane and others 2007). This comparison is stratified by potential vegetation (biophysical setting; BpS) within each ecological subsection (Cleland and others 2005) for a given LANDFIRE mapping zone. This combination defines the spatial grain of LANDFIRE FRCC maps. A metric of departure is then calculated and summarized over each ecological subsection using the interagency FRCC methodology described by Hann and others (2004). This metric describes the magnitude of difference between the best available estimate of historical vegetation dynamics and currently measured vegetation dynamics. Maps of fire regime group, fire return interval, and fire severity are developed from intermediate products of the LANDSUM landscape succession model used to simulate historical wildland fire dynamics and vegetation reference conditions.

### LANDFIRE potential vegetation

LANDFIRE uses the ecological concept of potential vegetation (Daubenmire 1966; Pfister and Arno 1980) to stratify or compartmentalize the landscape for mapping wildland fuel, for simulating historical vegetation and wildland fire dynamics, and for summarizing FRCC. There are two LANDFIRE potential vegetation data products: 1) Environmental site potential (ESP) and 2) Biophysical settings (BpS). Environmental site potential is used as an environmental stratification for wildland fuel mapping and as a precursor to the BpS mapping process. Biophysical settings serve as a spatial template for

simulating the ecological processes of succession and disturbance which are modeled aspatially using the vegetation dynamics development tool (VDDT).

Environmental site potential

The LANDFIRE Environmental Site Potential (ESP) map represents vegetation that could be supported at a given environmental site based on the biophysical environment (for example, species competition, topography, and climate). Map units are named according to NatureServe's Ecological Systems map unit classification, which is a nationally consistent set of mid-scale ecological units (Comer and others 2003). As used in the ESP map, map unit labels represent the natural plant communities that could occur at late or climax stages of successional development in the *absence* of disturbance. They are a reflection of vegetation constrained by climate and the physical environment, as well as by the competitive potential of native plant species.

The map unit classification for ESP is based primarily on floristics and uses both the qualitative descriptions of the Ecological Systems classification (Comer and others 2003) and the LANDFIRE existing vegetation map unit classification as a foundation.

Field training plots are assigned to map units using sequence tables. Sequence tables are developed based on input from regional ecologists and field-referenced data in the LANDFIRE reference database. Each row in the table is similar to a branch in a dichotomous key, with the presence and abundance of indicator species serving as the primary discriminating criteria. Geographic parameters are included as secondary discriminating criteria. Environmental site potential map units are arranged in a specific sequence in the table, just as branches in a dichotomous key would be. Sequences are based on gradients of ecological amplitude and competitive potential of indicator species. The relative importance of these characteristics in the LANDFIRE sequence tables is determined by geography and ecological regions defined by ECOMAP (Cleland

and others 2005), The Nature Conservancy's ecological regions, EPA ecoregions (Omernick 1995; EPA 2007), and LANDFIRE mapping zones. Once plots in the LANDFIRE reference database are keyed to ESP units, they are used as training data in the development of ESP maps. Classification trees are developed using these plot data against a suite of biophysical gradient layers, as described in Holsinger and others (2006b) and at www.landfire.gov. An iterative, stratified approach is used where mapping models are created using classification trees and evaluated against field-referenced data. The LANDFIRE ESP concept is similar to that used in other classifications of potential vegetation, including habitat types (Daubenmire 1966; Pfister and others 1977) and plant associations (Henderson and others 1989). It is important to note here that ESP is an abstract concept and represents neither current nor historical vegetation. The ESP map is very similar in concept to the potential vegetation map created for the LANDFIRE Prototype Project (Frescino and Rollins 2006). The ESP data product is an important precursor to the BpS data product.

Biophysical Settings

The Biophysical Settings (BpS) map represents vegetation that can potentially exist at a given site based on the physical environment, the competitive potential of native plant species, and a presumed historical disturbance regime. As in the ESP map, BpS map units are labeled using NatureServe's Ecological Systems classification (Comer and others 2003). As with the ESP map, LANDFIRE's usage of Ecological Systems for the BpS map differs slightly from the original intent of Ecological Systems as units of existing vegetation. As used here, map unit names represent natural plant communities that would become dominant in later stages of successional development considering historical ecological disturbance processes such as fire. The inclusion of natural disturbance regimes in the definition of BpS map unit definitions forms the main difference between the ESP and BpS maps.

The LANDFIRE BpS map evolves from the ESP map. ESP map units are either divided or aggregated based on differences or similarities in historical fire regimes. Fire regime information used to modify ESP map units is acquired from: 1) the qualitative descriptions of Ecological Systems in Comer and others (2003), 2) the LANDFIRE ModelTracker Database (MTDB) compiled through regional workshops held by The Nature Conservancy (described later in this document and at www.landfire.gov), 3) communications and iterative review by local ecologists and fire managers, and 4) existing literature describing the relationships between fire and vegetation dynamics. Aggregates or divisions of ESP map units are based on a combination of plot data, biophysical gradient data, input from vegetation dynamics models, and classification tree models. The modified map units are merged with the original ESP map to create the BpS map. Local data sets are used to develop separate mapping models for BpS for landscapes where existing vegetation is highly departed from historical vegetation and local data exist describing historical vegetation conditions. In this way, available local data are incorporated into the LANDFIRE BpS maps. The BpS data product is similar in concept to the potential natural vegetation groups (PNVG) in previous mapping and modeling efforts related to Fire Regime Condition Class (see Schmidt and others 2002 and http://www.frcc.gov).These mapping efforts were important precursors to the LANDFIRE Project's fire regime products.

## Simulating historical reference conditions

### Overview

In the context of LANDFIRE data products, reference conditions represent simulated historical vegetation composition and structure resulting from historical disturbance occurrence and severity (Pratt and others 2006). Reference conditions may be used as a baseline for evaluating current landscape conditions in terms of ecological departure from historical conditions (Hann and Bunnell 2001; Hann and others 2003, Holsinger and others 2006). LANDFIRE uses a

sequence of two landscape simulation models to develop historical reference conditions: 1) The Vegetation Dynamics Development Tool (VDDT), which provides a non-spatial state and transition modeling framework for modeling the role of various disturbance agents in vegetation change over time (Beukema and others 2003a); and 2) LANDSUM, a spatially explicit fire and vegetation dynamics simulation model (Keane and others 2006). LANDSUM incorporates aspatial vegetation dynamics models (hereafter referred to as vegetation models) developed using VDDT and applies them spatially to unique biophysical settings within the simulation landscape. This vegetation modeling framework, along with estimates of the temporal variability of climatic and disturbance rates, are used to spatially simulate historical reference conditions for fire frequency, fire severity, and vegetation composition and structure (Keane and others 2007).

Although many landscape simulation models exist, LANDFIRE selected LANDSUM because of the minimal number of inputs required and its generalized structure, which allows it to be portable, flexible, and robust with respect to geographic area, ecosystem, and disturbance regime (Keane and others 2002; Keane and others 2006). More complex models, such as Fire-BGC (Keane and others 1996) and LANDIS (Mladenoff 2004), may have generated more realistic landscape simulations, but the extensive parameterization required would likely have been impossible to implement consistently for every ecosystem in the United States. Also, to generate sufficient time series to characterize historical conditions, complex models such as these would have required prohibitively long computer processing duration. Less complex models, such as TELSA (Beukema and others 2003b) or SIMPPLLE (Chew and others 2004), would have been relatively easy to parameterize, but these models do not adequately simulate the spatial dynamics of fire spread and effects for evaluating landscape context and variation in landscape structure.  LANDSUM provides a good balance between the realism of more complex models and the simplicity of less complex models.

## Vegetation Dynamics Modeling

The objectives of LANDFIRE vegetation modeling were to 1) describe the myriad of disturbance information and transition times that entrain vegetation patterns over time, 2) to provide vegetation models for input to LANDSUM, and 3) to document the ecological assumptions and information behind the development of the models in the LANDFIRE Model Tracker Database (MTDB). The MTDB is a tool created in Microsoft Access used in LANDFIRE vegetation modeling to track inputs, outputs, assumptions, contributors, peer-review comments, and other data for each model. Information from the MTDB is used as ancillary data in the mapping of biophysical settings, existing vegetation type, succession classes, and surface and canopy fuels.

Vegetation models in the western United States were developed at 20 regional workshops where over 700 regional ecologists and fire managers developed over 1,200 vegetation models. At these workshops, vegetation and fire ecology experts synthesized the best available science and local knowledge on disturbance dynamics for the vegetation communities found in their region. Participants were trained in VDDT software and worked in groups to develop vegetation models for each BpS in their respective modeling zones. Extensive internal and external review processes followed model development.

LANDFIRE and VDDT

VDDT is a quantitative state-and-transition model that combines information about the rates and pathways of vegetation development over time and the probabilities and effects of ecological disturbances. VDDT returns output such as the overall percentage of a class over time and the likelihood of the occurrence of disturbances. The output of VDDT consists of two sets of pathways. One set describes succession and the associated number of time-steps required to transition from one succession class to another without disturbance. The other set describes disturbance, both in terms of the succession class that results from specific disturbances and the associated probability of that disturbance occurring

for that particular succession class (Long and others 2006). For extensive information about VDDT, see Beukema and others (2003a).

LANDSUM simulation

LANDSUM is a state-and-transition patch-level succession model combined with a spatially explicit disturbance model that simulates wildland fire using a cell-to-cell spread method (Keane and others 2002; Keane and others 2006; Pratt and others 2006). Stands are defined as contiguous, homogeneous regions of biophysical settings. LANDSUM uses the vegetation modeling framework, described above, to define disturbance-succession patterns during the simulation period. LANDSUM operates at an annual time–step. For each year, the model first simulates disturbance. The model iterates through all the stands in the landscape and, for each patch, cycles through all possible disturbances for the current BpS/succession class for that patch and stochastically determines if a disturbance occurs. Once a disturbance is modeled for a particular patch, the simulation year concludes for that patch and no further disturbances or succession can occur.

There are two different disturbance categories in LANDSUM: non-fire, or aspatial, and fire, or spatial. Non-fire disturbances are simulated in two steps: initiation and effects. Initiation is based on probabilities defined in the vegetation pathways. Effects are then modeled as a change in succession class based on a second set of probabilities, also defined in the vegetation pathways, unique to the succession class/disturbance combination.

Fire disturbances are modeled in three steps: ignition, spread, and effects. Like non-fire disturbances, fire ignitions are based on probabilities in the pathways. The probability is adjusted using a fire weather multiplier and a scaling factor based on stand size and average fire size. Once a fire has ignited, LANDSUM stochastically determines the size of the fire and then, based on wind and slope vectors, spreads this burned area over the landscape until it has reached the

calculated fire size or reaches an unburnable boundary. The fire spread occurs across stand boundaries; thus, fires can divide stands and create new stands. Fire effects are then simulated at the patch level for each of the new patches created by the fire. The model stochastically determines fire severity based on the probabilities for each fire severity type (non-lethal surface, mixed-severity, and stand-replacing fire) in the vegetation models for the succession class that occupied the patch prior to the fire. Finally, the model determines the post-fire succession class based on probabilities assigned to the pre-fire succession class/severity combination

For those stands where no disturbances occurred, the model simulates succession based on the transition times defined in the vegetation models. LANDSUM implements a multiple pathway succession approach using unique sets of succession pathways for each BpS. This approach assumes that all pathways of successional development will eventually converge to a stable or climax plant community (PVT) in the absence of disturbance (Kessell and Fischer 1981; Noble and Slatyer 1977; Arno and others 1985). Each simulation year, all undisturbed patches advance one year in age, and when a stand reaches the final age for the current succession class, the stand transitions to a new succession class based on the succession pathways defined in the vegetation models. See Keane and others 2002, Keane and others 2006, Pratt and others 2006, and Keane and others 2007 for detailed information about LANDSUM simulations in LANDFIRE).

### Characterizing current conditions: succession class mapping

The LANDFIRE Succession Class (S-Class) map represents the current successional state of vegetation as determined by comparing LANDFIRE existing vegetation data products (existing vegetation type, cover, and height) with the defined successional composition and structure rules outlined in each vegetation model (Holsinger and others 2006).

LANDFIRE succession classes categorize current vegetation composition and structure into up to five successional states defined for each BpS vegetation model: ’A’ to ’E’. Two additional categories define uncharacteristic vegetation: ‘UN‘ (uncharacteristic native vegetation) and ’UE‘ (uncharacteristic exotic vegetation). These are components that are not found within the compositional or structural variability of successional states defined for the BpS model. Exotics in the LANDFIRE EVT map are assigned a value of UE in the SClass map. Additional exotic vegetation types are mapped for each zone using field-referenced data, Landsat imagery, and gradients and are classified as ’UE.’ Agriculture and urban areas were removed from analysis of vegetation departure. LANDFIRE succession classes are similar in concept to those defined in the Interagency Fire Regime Condition Class Guidebook (www.frcc.gov).

Current conditions for each BpS are derived from the S-Class map by computing the percentage of each S-Class category within a defined area. Current conditions can then be compared to reference conditions computed at the same scale to obtain a measure of departure as described in the following sections.

## Creating the final LANDFIRE fire regime data products

Two types of LANDSUM output are used to develop LANDFIRE fire regime data products 1) vegetation time series data for the simulation period and 2) fire regime grids. The time series data that define reference conditions for vegetation are summarized in a tabular file that summarizes the area within each reporting unit occupied by each BpS/succession class combination for each reporting year. These data are used to calculate FRCC and departure values for each reporting unit (Holsinger and others 2006, Keane and others 2007). Fire frequency and fire severity grids are then processed to create the final LANDFIRE fire regime data products.

### Fire regime maps

LANDSUM outputs three fire severity maps and one fire frequency map which are then processed to create the final LANDFIRE fire regime data products. Fire severity in LANDSUM is defined as low-severity fire, mixed-severity, and replacement-severity. LANDFIRE produces maps for each of these severity types that display the percentage of fires of the given severity type experienced by a particular pixel (see www.landfire.gov for specific attributes of and metadata for these data products). Fire severity is calculated as the total number of fires of the given severity type divided by the total number of fires experienced by that cell times 100. Values for each map range from 0 to 100 and, for any cell, the sum of the three maps equals 100. The fire frequency map simply reports the fire return interval (in years) and is calculated as the total number of simulation years divided by the total number of fires occurring in that cell. The fire frequency and fire severity data products are integrated to create a map of fire regime groups. These groups are intended to characterize the presumed historical fire regimes within landscapes based on interactions between vegetation dynamics, fire spread, fire effects, and spatial context (Hann and others 2004). There are various definitions for fire regime groups (Hann and Bunnell 2001; Schmidt and others 2002; NIFC 2007). LANDFIRE refined the definition in the Interagency Fire Regime Condition Class Guidebook (Hann and others 2004; http://www.frcc.gov) to create discrete, mutually exclusive criteria (http://www.landfire.gov/NationalProductDescriptions12.php) appropriate for use with LANDFIRE's fire frequency and fire severity data products.

Fire regime condition class (FRCC) and FRCC departure maps

Vegetation reference conditions simulated using LANDSUM are aggregated to a spatial reporting unit defined by ecological subsections (Cleland and others 2005). Although subsections may be composed of one or more distinct polygons, all LANDFIRE FRCC calculations are performed at the level of the entire subsection rather than for each individual polygon within it. It is important to note, however, that subsections can be subdivided by the LANDFIRE mapping zone boundaries. In this case, the areas of a subsection in each zone are summarized

individually because LANDFIRE data are processed zone-by-zone. The tabular simulation results from each simulation reporting unit are added to each subsection that occurs within the unit boundary.

The yearly percentages contained in each S-Class in each BpS in each subsection are then summarized into a normalized median reference condition value for that S-Class (http://www.frcc.gov). A median is calculated from the vegetation time series for each S-Class, and this value is normalized across succession classes within a given BpS to ensure that the reference conditions always total 100 percent of the area in that BpS. The area in each S-Class in a given year is mutually exclusive of the other succession classes because a pixel can belong only to one S-Class at a time. However, summary metrics applied to the time series of S-Class areas are not guaranteed to be mutually exclusive. The normalized median for each S-Class is the relative proportion of the raw median for that S-Class compared to the sum of raw medians across all succession classes in a given BpS.

Current conditions are derived from spatial summaries of the LANDFIRE Succession Classes layer using the BpS and landscape summary unit data layers. Agriculture, urban, and non-vegetated areas are excluded from calculations of current conditions and FRCC. The current condition of an S-Class is the percentage of that S-Class in the LANDFIRE Succession Classes layer within the total wildland area of a given BpS in a given subsection.

The reference and current conditions for each BpS are compared in each subsection to calculate FRCC. Only vegetation conditions are used in LANDFIRE FRCC calculations; these calculations *do not* account for fire regime departure as described in the Interagency Fire Regime Condition Class Guidebook (Hann and others 2004) because of a lack of comprehensive estimates of current fire regime across the nation. This is important to note because FRCC analyses conducted for local assessments may be required to account for such fire regime departure.

In this case it would be necessary to define the ‘current’ fire regime (Hann and others 2004).

The detailed instructions for calculating FRCC may be found at http://www.frcc.gov and in Hann and others 2004 and Holsinger and others 2006. First, similarity is calculated by totaling the smaller of the reference or current conditions for each S-Class. This similarity is then subtracted from 100 to determine the departure value. This departure value is then assigned to every pixel in the BpS layer in the subsection to create the LANDFIRE FRCC Departure data layer. This departure value is classified to create the LANDFIRE FRCC data layer, in which departure values between 0 and 33 are assigned to FRCC I, departure values between 34 and 66 are assigned to FRCC II, and departure values between 67 and 100 are assigned to FRCC III.

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