Use of FIA Plot Data in the LANDFIRE Project

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Abstract.—LANDFIRE is an interagency project that will generate consistent maps and data describing vegetation, fire, and fuel characteristics across the United States within a 5-year timeframe. Modeling and mapping in LANDFIRE depend extensively on a large database of georeferenced field measurements describing vegetation, site characteristics, and fuel. The LANDFIRE Reference Database (LFRDB) incorporates existing data from numerous sources along with new data targeting specific ecosystems. This article describes the contribution of Forest Inventory and Analysis (FIA) data to the LFRDB. Plot selection, quality assurance procedures, and geoprocessing applied to FIA data in LANDFIRE are discussed. We also describe the use of FIA data as inputs to several modeling and mapping processes. Several characteristics of the FIA sample design and field methods are beneficial to modeling vegetation distributions in LANDFIRE. In addition, tree-level attributes afforded by FIA data are essential to developing canopy fuel layers and are generally unavailable from other existing datasets. Ongoing and potential collaboration between FIA and LANDFIRE is identified.

Introduction

LANDFIRE (Landscape Fire and Resource Management Planning Tools; www.landfire.gov) is a 5-year project begun in 2004 to provide consistent geospatial data on vegetation, fire, and fuel across the entire United States, regardless of ownership. Principal investigators in this multipartner project are the U.S. Department of Agriculture (USDA) Forest Service Missoula Fire Sciences Laboratory, the U.S. Geological Survey (USGS) National Center for Earth Resource Observation and Science, and The Nature Conservancy. LANDFIRE is sponsored by the Wildland Fire Leadership Council, which implements and coordinates the National Fire Plan and the Federal Wildland Fire Management Policy. LANDFIRE has been identified as a data and modeling system key to implementing a national strategy for addressing the Nation's wildland fire problems (U.S. GAO 2005).

Deliverable products from LANDFIRE include more than 20 spatial data layers and a comprehensive set of field-plot data. Spatial layers are raster datasets generated at 30-m^2 resolution and distributed on The National Map Web site (http://gisdata.usgs.gov/website/landfire). Final products will be delivered by Multi-Resolution Landscape Characterization (MRLC) map zone (USGS 2005b), with Western States' map zones scheduled for completion by the end of 2006, Midwestern and Eastern States' by 2008, and those in Alaska and Hawaii by 2009.

A critical element of LANDFIRE is the provision of all spatial data required to run FARSITE (Finney 1998). FARSITE is a widely used fire-spread simulation model. It requires fuel layers in addition to topographic, weather, and wind data. LANDFIRE generates two versions of mapped fire behavior fuel models (Anderson 1982, Scott and Burgan 2005), forest canopy height, canopy cover, canopy bulk density, and canopy base height. Elevation, aspect, and slope products (USGS 2005a) are distributed with the LANDFIRE fuel layers to provide the complete set of FARSITE spatial inputs.

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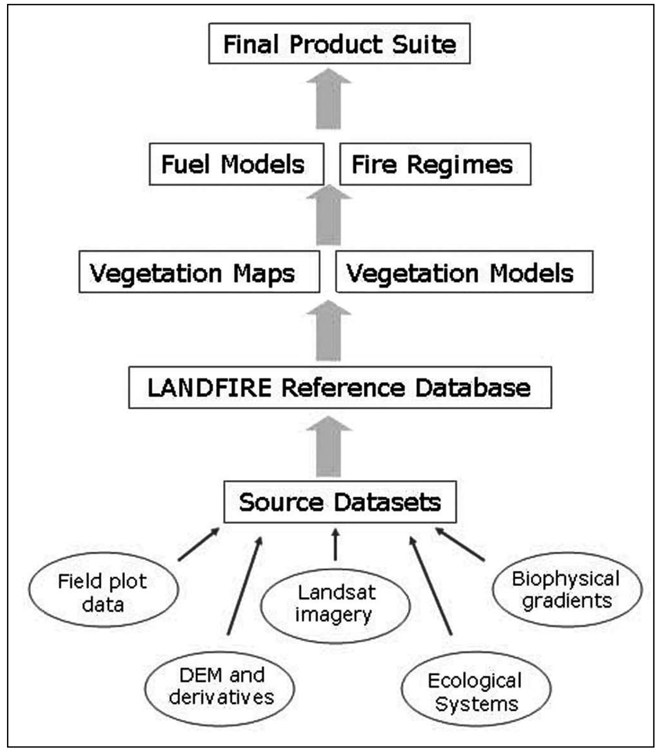
LANDFIRE also provides layers describing fire regimes and vegetation. Fire regime layers include fire regime condition class (FRCC) (Hann *et al.* 2003), FRCC departure, fire regime groups, fire return interval, and fire severity. Vegetation layers include environmental site potential, biophysical settings, existing vegetation type, existing vegetation canopy cover, existing vegetation height, and succession classes.

In this article, we briefly describe the process used to generate the LANDFIRE spatial products, with an emphasis on how Forest Inventory and Analysis (FIA) plot data are used in mapping and modeling.

LANDFIRE Process

LANDFIRE uses an integrative process incorporating satellite imagery, ecosystem simulation, vegetation modeling, and simulated landscape dynamics (Keane *et al.* 2002b, Rollins *et al.* 2004). Mapping is based extensively on a large database of georeferenced field measurements describing vegetation, site characteristics, and fuel. Multiple, independent screening procedures are applied to the plot data at various points in the process for quality assurance (QA). Plot data are associated with numerous additional attributes derived from spatial layers, vegetation classifications, and QA results. Figure 1 shows an overview of information flow in LANDFIRE.

Figure 1.—*Overview of the LANDFIRE process used to generate spatial data layers describing vegetation, fuel characteristics, and fire regimes.*



Source Datasets

Spatial Layers

Three dates of Landsat 7 imagery for each map zone are provided by the MRLC Consortium (USGS 2005b). A digital elevation model (DEM) and selected DEM derivatives are obtained from Elevation Derivatives for National Applications (USGS 2005a). Soil depth and texture layers are derived from the STATSGO database (USDA NRCS 2005b). Ancillary Geographic Information System (GIS) layers include roads (BTS 2005) and the 1992 National Land Cover Dataset (NLCD) (NLCD 1992, USGS 2005c).

LANDFIRE generates 42 simulated biophysical gradient layers (e.g., evapotranspiration, soil temperature, growing degree days) that become potential predictor variables in the mapping process. Biophysical gradients are generated using WX-BGC, an ecosystem simulator derived from BIOME-BGC (Running and Hunt 1993) and GMRS-BGC (Keane *et al.* 2002b). Inputs to WX-BGC are DAYMET interpolated weather data (Thornton *et al.* 1997), soil depth, soil texture, and elevation.

Vegetation Map Unit Classification

LANDFIRE vegetation mapping classification begins with NatureServe's ecological systems (Comer *et al.* 2003), with additional development by NatureServe and LANDFIRE ecologists. Ecological systems are defined by NatureServe as a group of plant community types that tend to co-occur within landscapes that have similar ecological processes, substrates, and/or biophysical gradients. They represent a mid-scale classification, smaller than ecoregions but larger than the associations and alliances at lower levels of the U.S. National

Vegetation Classification (USNVC) (Federal Geographic Data Committee 1997, Maybury 1999). The spatiotemporal scale for ecological systems is specified as tens to thousands of hectares, persisting for 50 or more years. At this spatial scale, ecological systems are mappable using remotely sensed data, while the temporal scale allows successional dynamics to be integrated into the concept of each unit.

Ecological systems provide the basis for map unit classifications of LANDFIRE existing vegetation types, environmental site potential, and biophysical settings. Existing vegetation type represents the vegetation currently present at a given site. Systematic crosswalks will link LANDFIRE existing vegetation type map units with the USNVC, the cover type classifications of the Society of American Foresters (Eyre 1980) and Society for Range Management (Shiflet 1994), and various agency classifications. Environmental site potential represents the vegetation that could be supported at a given site based on the biophysical environment. As used in LANDFIRE, map unit names for environmental site potential represent the natural plant communities that would become established at late or climax stages of successional development in the absence of disturbance. Environmental site potential is an abstract concept and represents neither current nor historical vegetation. Biophysical setting represents the vegetation that can potentially exist at a given site based on both the biophysical environment and an approximation of the historical fire regime. The biophysical settings map is a refinement of the environmental site potential map. As used in LANDFIRE, map unit names for biophysical setting represent the natural plant communities that would become established in later stages of successional development given natural ecological processes such as fire.

Field Plot Data

LANDFIRE obtains existing field data describing vegetation and/or fuel from numerous sources including the USDA Forest Service FIA program and other USDA Forest Service programs, the USGS Gap Analysis Program, Bureau of Land Management, Bureau of Indian Affairs, Department of Defense, Department of Energy, various State natural resource agencies, and university research labs. Vegetation data generally include some combination of the following: cover type, percentage cover by species or lifeform, heights and diameters of individual trees, crown ratios and crown classes of individual trees, and tree density. Fuel data generally include some combination of the following: counts or biomass estimates of fine and coarse woody material, percentage cover of live and dead shrubs and herbs, heights of the shrub and herb layers, and canopy base height. Plot photos are used if available. The data must include a georeference for each sampling point. LANDFIRE also samples a limited number of new field plots targeting systems underrepresented in the existing data.

Acquisition of FIA data begins with selected fields (table 1) from the Condition, Plot, Tree, and Seedling tables in the FIA database (Alerich *et al.* 2004, Miles *et al.* 2001) for all phase 2 plots (Reams *et al.* 2005). Tree canopy cover and understory species composition for each plot are also acquired where available regionally. Plot data are acquired from both the older periodic surveys (McRoberts 2005), as well as the annual inventories conducted since 2000 that use a national standardized plot design (Bechtold and Scott 2005). Down woody material data from FIA phase 3 plots are provided by the USDA Forest Service North Central Research Station (Woodall and Williams 2005). Data acquisition is coordinated with personnel from FIA Spatial Data Services (USDA Forest Service 2005) and designated FIA liaisons to the LANDFIRE project.

LANDFIRE Reference Database

Populating the LANDFIRE Reference Database (LFRDB) involves two phases: (1) compilation of plot records from disparate sources into a common data structure, and (2) associating the plot records with a large number of derived attributes. LFRDB structure and management tools are derived from the Fire Effects Monitoring and Inventory System (Systems for Environmental Management 2005). The compilation phase involves standardizing coordinate information, measurement units and species codes, along with initial QA screening. The second phase involves classifying plots to LANDFIRE existing vegetation type and environmental site potential, and performing spatial overlays to attribute plot records with topographic, gradient, and spectral values.

Table 1.—*FIA variables provided for use in LANDFIRE. Names of tables and national variables are from FIA database.*

Variable	Description	Availability
Plot table		
STATECD	State code	National
CYCLE	Cycle number	National
SUBCYCLE	Subcycle number	National
UNITCD	Unit code	National
COUNTYCD	County code	National
PLOT	Plot number	National
MEASDAY	Measurement day	National
MEASMON	Measurement month	National
MEASYEAR	Measurement year	National
DESIGNCD	Plot design code	National
Condition table		
CONDID	Condition identifier	National
CONDPROP	Condition proportion	National
LANDCLCD	Land class code	National
FORTYPCD	Forest type code	National
CRCOV	Tree crown cover	Regional
DSTRBCD1, DSTRBCD2, DSTRBCD3	Disturbance codes	National
DSTRBYR1, DSTRBYR2, DSTRBYR3	Disturbance years	National
TRTCD1, TRTCD2, TRTCD3	Stand treatment codes	National
TRTYR1, TRTYR2, TRTYR3	Stand treatment years	National
Tree table		
SUBP	Subplot number	National
TREE	Tree number	National
STATUSCD	Tree status code	National
SPCD	Species code	National
DIA	Current diameter	National
HT	Height	National
ACTUALHT	Actual height	National
CR	Compacted crown ratio	National
CCLCD	Crown class code	National
TPACURR	Trees per acre	National
HTTOCR	Height to crown	Regional
UNCR	Uncompacted crown ratio	Regional
Seedling table		
SUBP	Subplot number	National
SPCD	Species code	National
COUNTCD	Seedling count code	National
Other tables		
Various	Understory species composition	Regional

Source: Alerich et al. *2004, Miles* et al. *2001.*

Compilation of FIA Plot Data

The current national design for FIA ground plots uses clusters of four 24-ft radius subplots totaling approximately 1/6th ac. The minimum circle enclosing all four subplots is approximately 1.5 ac. A mapped-plot feature of the design specifies protocols by which field crews delineate areas within subplots recognized as distinct condition classes based on a predetermined set of discrete variables classifying land use, forest type, stand size, regeneration status, tree density, stand origin, ownership group, and disturbance history (Bechtold and Scott 2005). Although the motivation for the current plot design relates to avoiding statistical bias and domain classification problems, the condition-class information also allows users to make assumptions about the degree of heterogeneity in the plot footprint. It should be noted that before implementation of the national core design in the late 1990s, FIA units used a variety of plot designs with different approaches to positioning plots relative to condition-class boundaries (Bechtold and Scott 2005).

At present, LANDFIRE incorporates data from single-condition FIA plots only. Single-condition plots are assumed to have reasonably homogenous vegetation over the area of the plot footprint, and therefore to be more appropriate for associating with specific pixel values in raster datasets, compared with multiple-condition plots in general. Only the most recent measurement is used for plots sampled more than once over time. Initial QA procedures during compilation include linking all species nomenclature to PLANTS database codes (USDA NRCS 2005a), range validation of canopy cover, height values, and dates, and checking coded attributes against lookup tables. Source documentation is maintained to an extent that would allow FIA personnel to trace a record in the LFRDB back to the original internal FIA dataset.

Derived Attributes

Automated sequence tables are used to assign plots to vegetation map units (ecological systems) for existing vegetation type and environmental site potential. The sequence tables encode rule sets for classifying plots based on life form canopy cover values and relative abundance of indicator species. Species composition data for FIA plots are derived from Tree and Seedling records and understory vegetation records where available (e.g., Interior West, Pacific Northwest).

Spatial overlays are performed to associate plot records with approximately 100 raster data layers (fig. 2). These derived attributes become potential predictor variables in the mapping process described below. Coordinates for FIA plots are not stored in the LFRDB. Geoprocessing and spatial analysis are done by designated FIA liaisons to the LANDFIRE project for compliance with FIA confidentiality and security requirements.

LFRDB Summary to Date

LFRDB compilation was complete for eight map zones as of September 15, 2005 (fig. 3). There were 71,664 potentially usable plot records for these eight map zones. Two percent of these plots (1,446) were withheld from mapping for use in accuracy assessment. Overall, 15 percent of plots were from FIA, while 31 percent of plots in woodland and forest cover types were from FIA. Table 2 shows summary characteristics for FIA plots and non-FIA plots as a group. Non-FIA plots tended to be clustered nearer to roads compared with FIA plots that are positioned to provide a broad-scale statistical sample based on a hexagonal frame with spatial intensity of one plot per 6,000 acres in the population of interest (Reams *et al.* 2005).

Figure 2.—*Geoprocessing to generate derived spatial attributes for field plot records.*

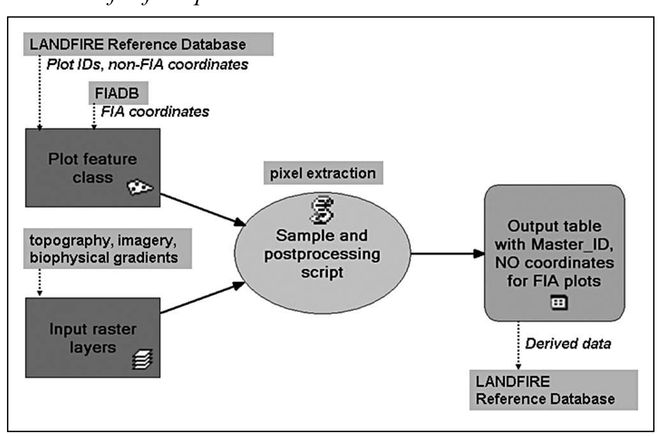
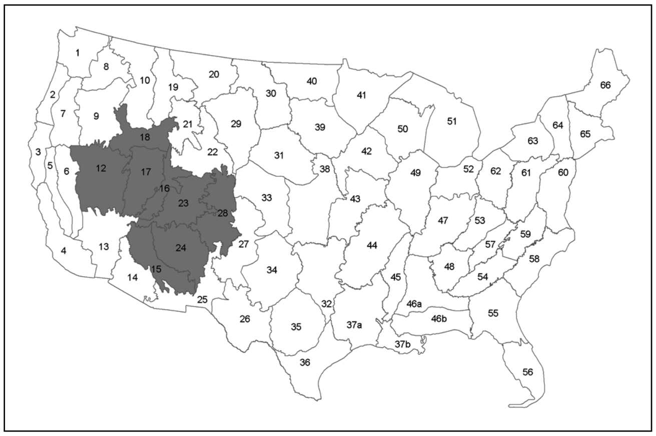


Figure 3.—*LANDFIRE map zones for the coterminous United States. Shading indicates zones for which LFRDB compilation was completed as of September 15, 2005.*



LFRDB = LANDFIRE Reference Database.

Table 2.—*Summary characteristics of FIA plots and non-FIA plots as a group from the first eight map zones[a] of the LFRDB.*

Characteristic	FIA plots	Non-FIA plots
Average distance to nearest road[b]	985 m	396 m
Spatial pattern	Dispersed	Clustered
Temporal span	1978–2004	1984–2004

FIA = Forest Inventory and Analysis; LFRDB = LANDFIRE Reference Database.
[a] Map zones 12, 15, 16, 17, 18, 23, 24 and 28.
[b] Based on U.S. Bureau of Transportation Statistics (2005) roads layer

Vegetation Mapping

Vegetation maps, both existing vegetation type and environmental site potential, are foundational to LANDFIRE fuel and fire regime products. The general approach to mapping is based on classification trees (e.g., Huang *et al.* 2003) using See5 software (www.rulequest.com). Thousands of plots per map zone from the LFRDB are available as training sites for supervised classification. Plots are subjected to two separate QA screening procedures before mapping. Approximately 100 potential predictor variables are associated with plot records, describing topography, biophysical gradients, and spectral reflectance (satellite imagery is not used for mapping environmental site potential or biophysical setting). Classification-tree output from See5 is applied spatially using custom software to produce the vegetation maps.

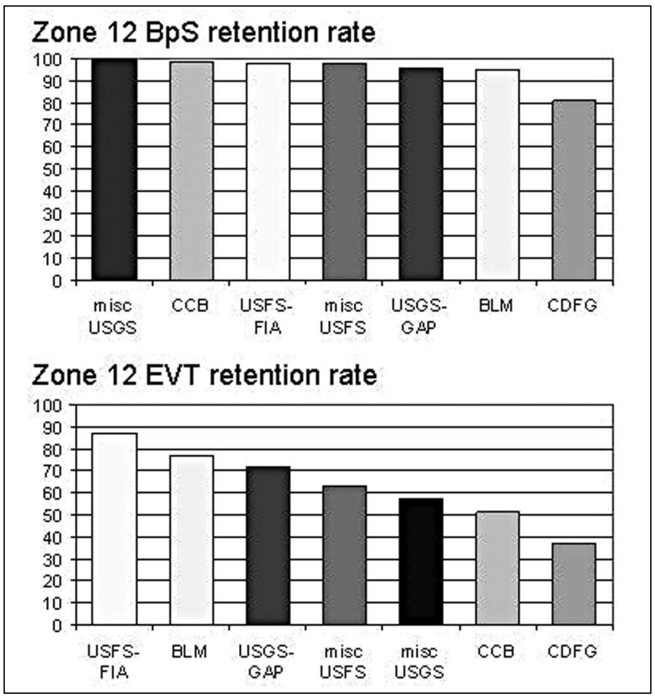
QA Screening Procedures

QA screening of plots before mapping environmental site potential and biophysical setting attempts to identify plots that have been misclassified by the sequence table. Plots could be misclassified due to incomplete species composition data, recent disturbance that affects species composition on the plot, or errors in the sequence table. Initially, a subset of plot records is flagged based on unlikely combinations of environmental site potential and existing vegetation type. The flagged plots are examined further by manually reviewing species composition data and plot photos if available. The process also makes use of disturbance history information if available, including FIA disturbance (DSTRB) and treatment (TRT) codes.

QA screening prior to mapping existing vegetation type examines assumptions inherent to integrating satellite imagery with the plot data. The procedure attempts to reconcile point-in-time differences between plot measurement date and image acquisition date. Initial flagging of plots is based on distance to nearest road, lack of agreement between the plot dominant life form and NLCD, and recent disturbance on the plot if disturbance history data are available. In addition, a threshold value of Normalized Difference Vegetation Index difference produced from MRLC 1992 and MRLC 2001 (USGS 2005b), indicating areas of likely change, is also used to flag potential problem plots. Flagged plots are examined visually, overlaid on satellite imagery.

QA screening represents a significant investment in analyst time before vegetation mapping due to the requirement for manual inspection of plot records in both tabular and spatial contexts. QA attributes in the LFRDB denote which plots were discarded from mapping, reason codes for the discarded plots, and analyst notes. Retention rate is the percentage of plots retained for mapping after QA screening. FIA plots tend to exhibit high retention rates relative to other data sources in the LFRDB (fig. 4).

Figure 4.—*Percentage plot retention by data source following quality assurance screening for existing vegetation type (EVT) and biophysical settings (BpS) mapping in LANDFIRE map zone 12. Data sources are USGS Nevada and Utah Gap Analysis Programs (USGS-GAP), USDA Forest Service FIA program (USFS-FIA), various USDA Forest Service vegetation mapping and related efforts (misc. USFS), Stanford University Center for Conservation Biology (CCB), Bureau of Land Management Ely field office (BLM), California Department of Fish and Game (CDFG), and USGS monitoring effort within the Nevada Test Site (misc USGS).*



Vegetation Models and Fire Regimes

Although vegetation modeling and fire regime mapping are major components of LANDFIRE, they are described here only briefly because they do not use FIA data directly. Vegetation models quantify succession and disturbance dynamics for each biophysical setting (Pohl *et al.* 2005). They are aspatial, state-and-transition models developed through a series of regional expert workshops using Vegetation Dynamics Development Tool (VDDT) software (ESSA Technologies Ltd. 2005). Development of the models involves specifying successional states for each biophysical setting, along with temporal parameters and probabilities for transition pathways between states. Extensive documentation and peer review accompany model development.

The VDDT models, along with maps of biophysical setting and topography, and parameters for fire and climate, are inputs to a spatially explicit Landscape Disturbance and Succession Model (LANDSUM) (Keane *et al.* 2002a). LANDSUM simulates historical vegetation and fire regime characteristics. Output from LANDSUM is used to generate the LANDFIRE fire regime maps. Combined with maps of existing vegetation succession classes, LANDSUM reference condition output is used to generate maps describing vegetation departure (e.g., FRCC).

Fuel Layers

Fuel Loading Models

LANDFIRE fuel loading models contain information about specific live and dead fuel amounts that can be used to predict fire effects such as soil heating, vegetation mortality, and smoke. They are based on a classification comprising 14 fire effects groups. Coarse woody debris, duff, and litter are important discriminants. Development of fuel loading models is informed by FIA phase 3 down woody material (DWM) data (Woodall and Williams 2005), and DWM data from FIA phase 2 plots where available (e.g., Pacific Northwest FIA).

Canopy Fuel Layers

LANDFIRE maps the FARSITE canopy fuel layers, canopy bulk density (CBD), and canopy base height (CBH) directly from field data using methods similar to those described above for vegetation mapping. CBD is the volumetric density of available canopy fuel (kg/m^3), based on dry weight of material greater than 0.25-in diameter. CBH is defined as the lowest height above ground with sufficient fuel to propagate fire vertically, starting where CBD is greater than or equal to 0.012 kg m^{-3}. CBD and CBH are estimated from plot data using FuelCalc software (Reinhardt *et al.* 2006). FuelCalc implements a set of species-specific biomass equations to estimate CBD and CBH along with available canopy fuel and total canopy weight. Tree-level inputs to FuelCalc are species, diameter at breast height, height, height to base of live crown, crown class, and (plot-level) trees per acre.

FIA data generally afford the required inputs to FuelCalc, whereas most other data sources in the LFRDB do not provide this full set of attributes. A caveat is that height to base of live crown is derived from the tree crown ratio. The FIA national core variable is compacted crown ratio (CR), the percent of the tree bole supporting live, healthy foliage, with the crown visually compacted to fill in gaps, expressed as a percentage of total tree height (Alerich *et al.* 2004). Compacted crown ratio has long been considered an indicator of tree vigor and an important predictor of periodic growth increment in forest growth models (e.g., Wykoff *et al.* 1982). In fire behavior modeling, however, a major interest is on the vertical continuity of fuel from the ground to the crown as a predictor of crown fire risk. Height to base of live crown derived from uncompacted crown ratio is a more appropriate variable for these applications (Monleon *et al.* 2004). Uncompacted crown ratio is available regionally for some FIA plots (e.g., Interior West, Pacific Northwest).

Conclusions

Use of FIA data has clear benefits for LANDFIRE. FIA provides a national, consistent dataset that is continually updated. Data quality is high, resulting in high retention rate for plots subjected to LANDFIRE QA screening procedures. The even spatial distribution of FIA plots is beneficial for mapping at regional scales. Condition-class information from the mapped-plot feature of the national FIA plot design can potentially be exploited to improve integration with remotely sensed data. Furthermore, FIA data contain a rich set of attributes including species composition, stand structure, down woody material, and tree-level inputs for FuelCalc estimation of canopy fuel. The full set of FuelCalc inputs is not generally available from other data sources.

A limitation of FIA data for mapping vegetation and fuel characteristics at a national extent is the regional availability of certain attributes. These include plot-level tree canopy cover, understory species composition, and uncompacted crown ratio. While these attributes are available for FIA phase 2 plots in the Interior West and Pacific Northwest regions, national mapping projects using FIA data may be required to choose between altering methodologies across regions or accepting FIA national core variables for wall-to-wall coverage. Despite this limitation, FIA is more consistent on a national basis compared with other existing datasets in terms of attributes available, sampling design, and field methods.

The collaborative relationship with LANDFIRE also has benefits for the FIA program. LANDFIRE provides a national application of FIA data to wildland fire management through development of an integrated data and modeling system. FIA plots processed by LANDFIRE comprise a value-added data set with potential application to other mapping efforts. LANDFIRE attributes FIA plots with ecological systems classification, quantitative vegetation models, biophysical gradients, predicted fire regime characteristics, and a set of QA attributes relevant to integrating plot data with satellite imagery, vegetation classification, and fuel mapping. Software tools developed for geoprocessing and exploratory data analysis in LANDFIRE also could have broader utility within FIA.

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