Review and assessment of LANDFIRE canopy fuel mapping procedures

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Executive Summary

The LANDFIRE procedures for quantifying and mapping canopy fuel characteristics follow generally accepted scientific procedures in the fields of fuel science and remote sensing. Accuracy of LANDFIRE canopy fuel products is low, but consistent with constraints imposed by the very large (national) extent of the effort and the high inherent variability of the characteristics being mapped. Other canopy fuel mapping efforts have achieved greater accuracy than LANDFIRE's products, but at greater cost per acre mapped, and by employing methods that can't be applied at LANDFIRE's extent. The problem of low map accuracy of LANDFIRE canopy fuel products is a greater problem for project-level geospatial fire analyses than for the national-level analyses which LANDFIRE was designed to support. Insufficient accuracy can be resolved by end users through a routine process of critique and calibration (refinement using local information) and refreshing (to account for changes in the landscape since the effective date of LANDFIRE products). Work is now underway to develop a standard procedure for critiquing and calibrating LANDFIRE data layers and to refresh the LANDFIRE data to the present time. These efforts will improve accuracy for both project- and national-level analyses.

Artificial seams in LANDFIRE data products may exist both within and between map zones. The problem of data seams is very difficult to resolve once the data have been published by LANDFIRE, but are unavoidable given the scale and constraints of the project. The utility of LANDFIRE data for national-level analyses is not significantly compromised by these seamlines, but regional- and project-level analyses may suffer from the difficult-to-remove seams.

This report is organized around seven potential shortcomings or problems with canopy fuel related LANDFIRE data products:

- canopy cover values are too high,
- data discontinuities exist within and between map zones,
- canopy bulk density values are too low for use in FARSITE,
- canopy base height is too high to generate crown fire,
- treelist data sources may not be best for canopy fuel calculations
- alternative canopy fuel calculation programs may produce different results
- Refreshing and calibrating LANDFIRE data is needed

Canopy Cover values too high

The canopy cover values used in the LANDFIRE process were obtained from the National Land Cover Dataset (NLCD). The NLCD dataset was produced using a Classification and Regression Tree (CART) analysis relying on a method combining satellite remote sensing and field data. Unfortunately, there are several cover-related quantities measured by ecologists and used by fire modelers; the different quantities are frequently interchanged, erroneously.

As used in fire modeling software and envisioned by fire behavior specialists, canopy cover is the proportion of the forest floor covered by the vertical projection of tree crowns. Some field methods estimate this quantity without bias, but the most common field measurement technique uses a spherical densitometer that actually measures a quantity sometimes called canopy *closure*—the proportion of the sky hemisphere obscured by vegetation when viewed from a single point. Canopy closure is usually a higher value than canopy cover; canopy cover rarely exceeds about 70 percent, whereas canopy closure often approaches 100 percent. Refer to the FireWords glossary of fire science terminology (Scott and Reinhardt 2007) for more details (available at www.fs.fed.us/fmi/downloads/firewords.html). It is not clear if this is the reason for the discrepancy between the NLCD canopy cover values and on-the-ground experience. Nonetheless the canopy cover values produced by NLCD are acknowledged by the LANDFIRE developers to be too high relative to the quantity used by existing fire models.

Canopy Cover is a key LANDFIRE variable because it is used as an independent variable for estimating a wide range of dependent variables like fuel model and canopy bulk density. As directly used in fire modeling programs, canopy cover is used to estimate wind adjustment factor and fine dead fuel moisture. The wind adjustment factor sub-model in fire modeling systems is relatively insensitive to the magnitude of apparent errors in the canopy cover maps. The dead fuel moisture model, however, is more sensitive to errors in canopy cover. In an unpublished analysis, LANDFIRE's Matt Reeves[1] found that correcting the apparent canopy cover error using an alternative approach resulted in a dead fuel moisture decline of roughly 2 percentage points across example landscapes. This change in fuel moisture led to modest changes in potential fire behavior as simulated with FlamMap[2], but a factor-of-two increase in fire growth using FARSITE[3], a significant increase.

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[1] Matt Reeves is a GIS Specialist and leads the LANDFIRE Fuels Team, stationed at the Missoula Fire Sciences Laboratory.

[2] FlamMap is software that maps potential fire behavior across a landscape for a single specified weather condition, and has features that allow simple fire growth simulation, identification of fire travel paths, and locating fuel treatments. Available at www.firemodels.org

[3] FARSITE is software that simulates the growth of one fire for one projected weather scenario. Available at www.firemodels.org.

Moreover, canopy cover mapping errors may lead to significant indirect fire modeling effects. Because canopy cover is a keystone variable, these indirect effects are difficult to quantify. If canopy cover is overestimated, LANDFIRE may subsequently map the incorrect fuel model, incorrect CBD, incorrect CBH, etc., all of which can strongly affect fire modeling outputs in a geospatial fire analysis. Using the current LANDFIRE fuel mapping procedure, Tobin Smail[4] believes these indirect effects may be small, because they are so heavily calibrated by end users before publication of the data.

Unfortunately, most of the direct and indirect effects of overestimating canopy cover tend to under-predict fire behavior; the effects are not necessarily compensating. For example, overestimating canopy cover in forested areas can lead to slight underestimation of midflame wind speed, slight-to-moderate overestimation of dead fuel moisture content, choosing a too-benign fuel model (one with little or no live fuel, for example). Together, these factors conspire to underestimate surface fire behavior. Overestimating canopy cover can potentially lead to overestimating canopy bulk density in the LANDFIRE process, which in some cases can partially balance the underestimation.

Because it is used as an independent variable, the importance of an accurate canopy cover layer in the LANDFIRE process should not be underestimated. Matt Reeves reports that a newer type of FIA plot allows independent calculation of canopy cover for FIA plots installed since 2005. This new method appears to agree well with the unbiased (but infrequently used) line-intercept field method of estimating canopy cover, whose values correlate very well with what is expected in the fire behavior models, without manipulation. If enough of such plot data is available, it may be possible for LANDFIRE to generate canopy cover maps using this new approach, with significant improvement in fire modeling. Such improved canopy cover maps may also affect dependent LANDFIRE maps such as CBD.

[4] Tobin Smail is a LANDFIRE fuel specialist based at the Missoula Fire Sciences Lab.

Seamlines within and between map zones

LANDFIRE data is “gapless” because it maps fuel and vegetation characteristics across all ownerships across the U.S. That is a critical feature because important aspects of geospatial fire analysis (fire growth modeling and mapping potential fire behavior and effects) require gapless coverage of not only the analysis area but of a large buffer around the area as well. However, despite using a consistent methodology across the U.S., LANDFIRE data is not “seamless” in the sense that obvious artifacts of the mapping process are evident in surface and canopy fuel layers. Seams in LANDFIRE maps can arise from two sources. First, a seam can exist along map zone boundaries, even if the satellite imagery were the same in both map zones, because different protocols and different fuel and fire experts can be used in each map zone. Second, a seam may exist *within* a map zone due to the developers’ need to stitch satellite scenes into a composite image for a whole map zone. This procedure is similar in nature to stitching together digital photos to make a panorama—if the exposure is not the same for each photo, then the boundary between photos becomes obvious in the final panorama. In the LANDFIRE process, if those separate satellite images are of similar quality (captured during times of similar atmospheric conditions, for example) then the compositing process works well and a seam may not be created. However, the separate images may differ in many respects (primarily atmospheric conditions) such that the information contained in one image may differ from another image for the same pixel. The CART analysis assumes that all variation in the images is due to on-the-ground differences, not atmospheric differences unrelated to actual differences on the ground. When used in subsequent CART analyses, the boundaries where the two images were merged can become a noticeable data seam where the map indicates a strong change in value that is not actually present on the landscape. This is a difficult problem to reconcile; there is no easy way to remove such a seam—it’s in the base imagery that the data layers are built upon, and it runs along an artificial (satellite image) boundary. Such data seams can also exist in the inherited NLCD canopy cover data used in the LANDFIRE fuel mapping process, but those seams are generally “hidden” along natural terrain features such as rivers and major ridgelines where changes in vegetation structure are not uncommon. Despite being hidden, such seams can produce disconcerting data discontinuities in the final map.

For example, Charley Martin[5] provided this LANDFIRE CBD data for southern Oregon, which shows the distribution of CBD values in a small watershed that crosses a map zone boundary (figure 1).

[5] Charley Martin is a Fire Ecologist with the Bureau of Land Management’s Medford District, Oregon. Charley has been closely involved in LANDFIRE’s calibration workshops and participated in a separate project to assess accuracy of LANDFIRE fuel maps.

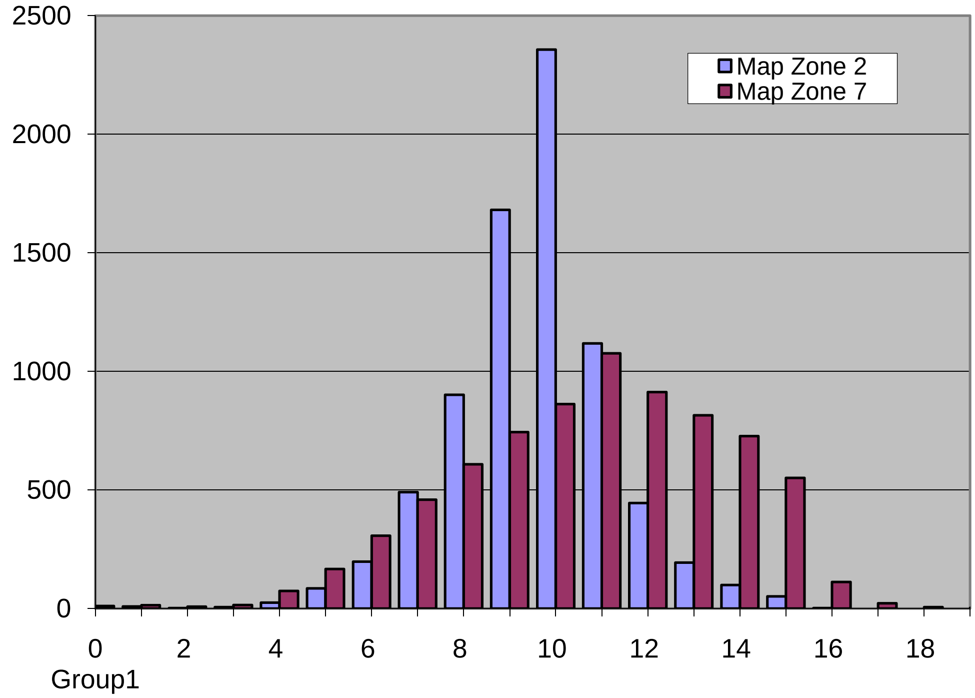

Figure 1 -- Distribution of CBD values (kg/m3 * 100) for a southern Oregon watershed that crosses two map zones .

The expectation, based on field experience in the watershed, is that the distributions should have the same shape. Information such as this can help in a calibration exercise designed to force the map zones into similar distibutions, but there is no way to know which distibution is “correct”. The following map (figure 2) shows the nature of the data discontinuity on the CBD map. Similar data seams are evident in nearly all LANDFIRE maps for this watershed.

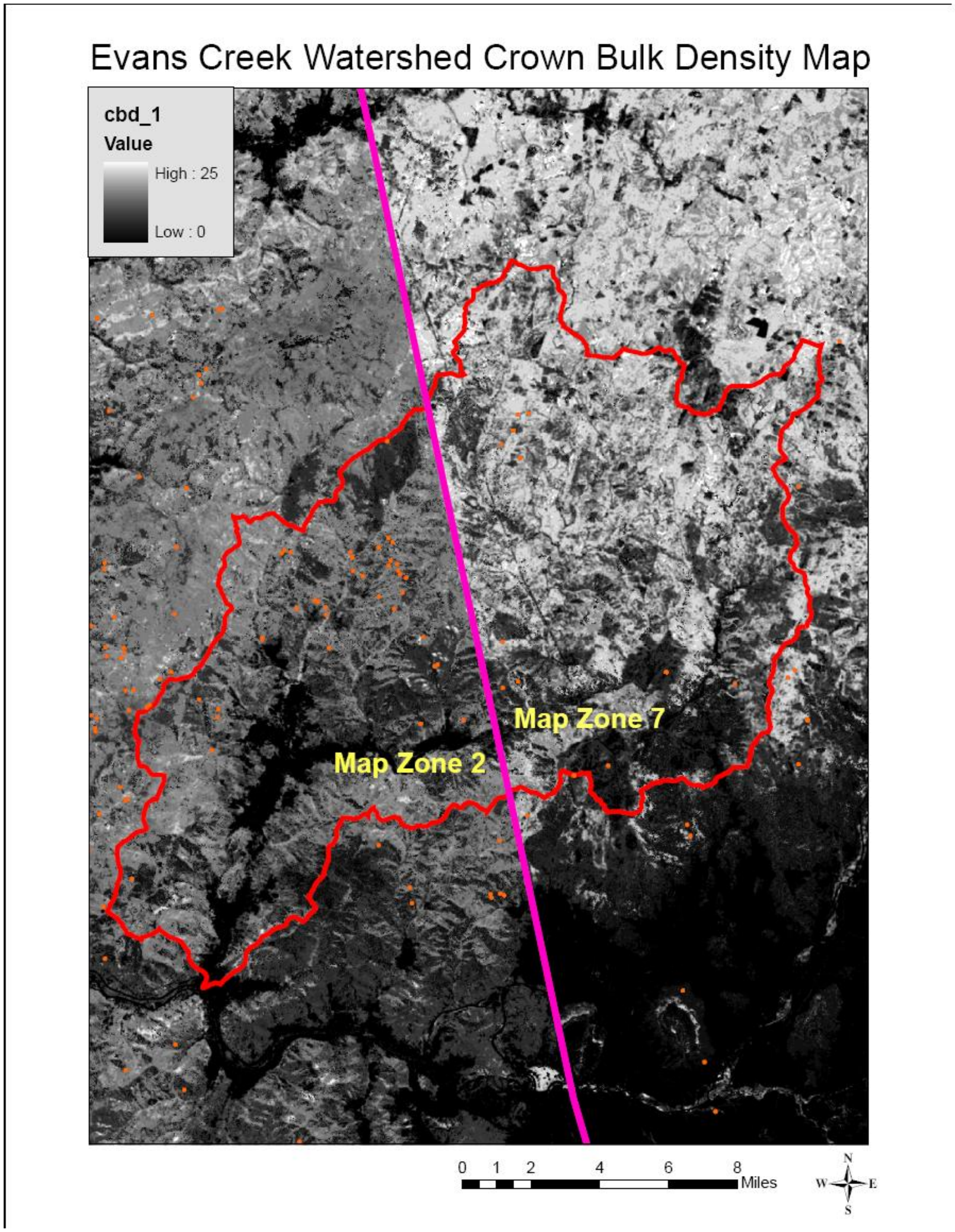

Figure 2 -- LANDFIRE map of CBD in a watershed crossing the map zone 2/7 boundary. CBD is shown as higher in the Map Zone 7 portion of the watershed; on-the-ground experience does not support that result.

Rick Stratton[6] of Systems for Environmental Management[7] is currently working on a procedure for calibrating and updating LANDFIRE data for use in some fire modeling

[6] Rick Stratton is a Fire Modeling Specialist with Systems for Environmental Management, based at the Missoula Fire Sciences Lab.

systems. Fire Program Analysis (FPA) and the USDI National Park Service are co-funding that work. The current in-preparation version of Stratton's work does not yet suggest a method for mitigating seams. Charley Martin, with the BLM in Oregon, is trying an approach that smoothes the data on both sides of the seam to reduce its effect. Such an approach is visually appealing on a map, but does not effectively deal with the problem.

Alternative approaches to using remote sensing imagery in creating the LANDFIRE data layers may reduce the intensity or extent of seams. An alternative approach, which avoids seamlines by conducting the mapping and analysis one strip (satellite image) at a time, rather than one map zone at a time, is being used to generate LANDFIRE maps in Alaska. This approach requires that field data be well-distributed across the area, because sufficient field data must exist within each image, not just the map zone. Assuming such data exist, this approach may work well to avoid seamlines and improve accuracy.

Seamlines in LANDFIRE data primarily affect project-level analyses, but regional- and national-level analyses may also be affected. Even a national analysis like FPA is broken into smaller units (FPUs and FMUs) for analysis and comparison. If the analysis unit is small compared to the map zone or satellite imagery, then the potential exists for the data discontinuities to affect results. The larger the analysis area, the smaller the effect seamlines will have on the results.

[7] Systems for Environmental Management (SEM) is a private, nonprofit research and education foundation based in Missoula Montana. In conjunction with federal partners, SEM has developed a host of fuel, weather and fire behavior modeling software and procedures, which are available at www.fire.org.

CBD too low for crown fire in the FARSITE family

Users of the Mark Finney's[8] family of geospatial fire analysis programs (FARSITE, FlamMap, FSPro[9], FSIM[10]) have long noted that values of canopy bulk density (CBD) produced by treelist methods are too low to generate the expected amount of crown fire in their simulations. LANDFIRE has used a prototype of FuelCalc, which applies a treelist method for estimating CBD, to generate its CBD map, so the complaint has been extended to LANDFIRE CBD maps. A general rule-of-thumb was developed to cope with this apparent disconnect: double the LANDFIRE treelist-generated values for use in Finney's geospatial programs to achieve the expected results.

Early CBD mapping procedures (Selway-Bitterroot, Gila wilderness areas) were developed before any plot-level methods of estimating CBD had been developed. Instead of relying on observed CBD at plots, the early efforts instead populated CBD by working backward from expected fire behavior to determine the CBD values that produce that behavior using a given fire model. Given the lack of plot-level CBD observations available at the time, the approach was reasonable. Nonetheless, that procedure produces a value that is good only for the particular fire model used. In this case, the fire model used, FARISTE, produces fire behavior quite different than all others developed since then (except FARSITE's geospatial relatives).

Since those initial mapping efforts, our ability to estimate CBD has improved considerably, and is codified in FuelCalc[11], Fuels Management Analyst Plus (FMAplus[12]), and the Fire and Fuels Extension to the Forest Vegetation Simulator (FFE-FVS), all of which use a treelist approach. Such methods are based on decades of biomass research. The CBD algorithm in FuelCalc was conservatively designed to over-estimate rather than under-estimate CBD (by using the highest CBD found in any 11-ft layer of a canopy as the value for the whole plot, which is commonly more than twice the average bulk density). Comparison of predicted CBD with meticulously observed CBD (Scott and Reinhardt 2005) has generally verified the utility of the approach for estimating CBD in various stand structures. The values the treelist method produces fall squarely in the

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[8] Mark Finney is a research forester at the Missoula Fire Sciences Lab. Mark is the developer of a suite of geospatial fire modeling software tools, including FARSITE, FlamMap, FSPro, and FSim.

[9] FSPro is online software that simulates the likelihood of fire spread across a landscape by simulating fire growth under a large sample of possible future weather scenarios. FSPro is an integral component of the Wildland Fire Decision Support System (WFDSS).

[10] FSIM is prototype software that simulates the likelihood of fire growth and behavior across a landscape for a sample of possible weather conditions and for a sample of possible escaped-fire frequencies and locations. FSIM simulations are being considered for use in FPA, and are also used in prototype quantitative wildland fire hazard and risk assessments.

[11] A prototype version of FuelCalc designed by Elizabeth Reinhardt at the Missoula Fire Sciences Lab was used by the LANDFIRE fuel staff. A more complete version of FuelCalc is currently under development.

[12] FMAplus is commercially available software produced by Don Carlton of Fire Program Solutions LLC, available at www.fireps.com.

range of values that Agee's (1996) analysis found would lead to crown fire. The treelist methods generate CBD values work well in all fire modeling software programs except Finney's geospatial family, including BehavePlus[13], FMAplus and NEXUS[14]. FlamMap and FARSITE offer users a choice of crown fire modeling methods to use: the original "Finney (1998)" method, and a method similar to that used in NEXUS, which is labeled "Scott and Reinhardt (2001)" in those programs (figure 3).

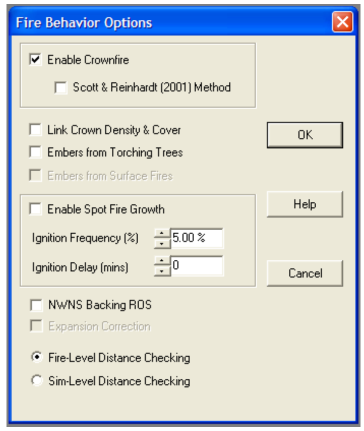

Figure 3--The *Model | Fire Behavior Options* dialog box in FARSITE, showing the checkbox that allows calculation of crown fire similar to the method described in Scott and Reinhardt (2001).

Users have generally found that using LANDFIRE or other treelist-generated CBD data with the crown fire option set to "Scott and Reinhardt" produces very reasonable results for crown fire occurrence, but not when using the "Finney 1998" default setting.

Scott (2006) suggests that the significant difference in fire model outputs (fire type, crowning index, etc.) between Finney's geospatial fire models and the others can be attributed to an error in modeling logic made initially in the Canadian Forest Fire Behavior System and subsequently used in Finney's programs. The error in modeling logic had little practical effect as implemented in the Canadian prediction system, so it went unnoticed; the same logic error when implemented in the U. S. system, however, has led to great differences in predicted fire behavior. See Scott (2006) for a detailed discussion of this topic.

The problem that LANDFIRE-generated CBD may be too low for use in Finney's geospatial fire models is best addressed by the fuel and fire modeling community, not by LANDFIRE. For users who wish to use those programs in their default setting (or those using FSPRO and FSIM, which do not yet have an option to use the Scott and Reinhardt 2001 method), the current rule of thumb may be appropriate. Otherwise,

[13] BehavePlus is software that allows simulation of fire behavior and effects for a specific point in space and time. Available at www.firemodels.org

[14] NEXUS is software that allows simulation of crown fire potential for a specific point in space and time. Available at www.fire.org

many users report that using the “Scott and Reinhardt” switch with LANDFIRE CBD maps produces acceptable results.

CBH too high for crown fire

At first glance this issue appears similar to the above issue with CBD, but in reality it is much more difficult to address. Unlike CBD, CBH is difficult to define in such a way that it can be measured in the field or estimated from a treelist. Moreover, CBH is not strongly correlated with other stand characteristics, making it difficult to produce reliable maps using the LANDFIRE approach (or any mapping approach, for that matter). For example, within any given forest type, CBH can be low in areas with low canopy cover, because there may have been little self-pruning in such a low-density stand, or CBH can be high if the stand has low cover because it was thinned. The LANDFIRE procedure can only broadly distinguish those cases.

Such difficulties led to the development of an alternative method of estimating CBH based on expert opinion. (Note that this is a similar approach taken for the Selway-Bitterroot and Gila mapping projects when faced with a lack of available CBD data.) The fuel and fire behavior experts did not offer their opinion of CBH directly, but instead were asked to identify the weather conditions that typically lead to torching (because CBH is used to predict when torching will occur). From that information, along with the fuel model and canopy cover already assigned, the CBH that leads to torching is then identified by working backward through the crown fire initiation model. This expert opinion CBH therefore depends on the fuel model and canopy cover for the area, as well as the weather conditions identified by the experts. Any errors in mapping of those layers, and any changes or adjustments made by users to those layers invalidate this CBH estimate—transition to torching would no longer take place at the identified threshold.

Fortunately, unlike with CBD, all point-based and geospatial fire models, regardless of developer, use CBH in the same way, so estimates of CBH made this way are valid in all U.S. fire modeling programs.

The difficulties with estimating CBH to simulate transition to crown fire cannot be resolved by LANDFIRE. The fire modeling community may need to find a different approach that is more amenable to mapping and less dependent on surface fire behavior (see Cruz and others 2004).

In most fire modeling systems, especially in Finney's geospatial models, the downside of conservatively estimating a low CBH is small compared to the downside of estimating a CBH that is too high. Until fire modeling uses a different approach, a stop-gap measure that LANDFIRE could employ is to modify the FuelCalc procedure for estimating CBH to identify the height of the lowest biomass of any density. Responsibility for this task lies not with LANDFIRE but with the fuel and fire behavior modeling community.

Treelist data sources

LANDFIRE has gathered treelist data from a variety of sources that use a variety of inventory methods. Two tree inventory methods are generally used: fixed-area plots and variable-radius plots (some tree inventories combine both methods). The treelist-based calculation methods used by LANDFIRE in FuelCalc are designed to be used with fixed-area plots of approximately 0.1 ac in size. The developers of that method felt that variable-radius plot may not adequately represent stand structure of a plot because it emphasizes sampling of large trees at the expense of small trees. For canopy fuel estimation, the contribution of a large number of small trees can be much more important than a small number of large trees, so it is important to have as much information as possible for those trees. Moreover, the trees sampled at a variable radius plot can be very far apart from each other, so their individual crown characteristics may not necessarily reflect growing conditions near the plot center.

Nonetheless, a large amount of treelist data available to LANDFIRE is of the variable-radius or hybrid plot type. The magnitude of potential problems with using variable-radius plots is unknown. In theory, the CBD predicted for a variable radius plot is probably slightly lower than if a fixed-area plot had been established at the same location, but this is impossible to know without research comparing the two approaches at the same plot.

For this report, a comparison of fixed-radius and variable-radius plot types was conducted using a dataset for a single even-aged ponderosa pine/Douglas-fir stand in western Montana. The dataset consisted of a complete list of tree attributes, including (X,Y) coordinates, of every tree on a square, 100 x 100 m (1-ha) plot. (The plot was established in 2006 by Elizabeth Reinhardt[15] to eventually test the use of upward-looking LIDAR for estimating canopy fuel characteristics.) From this complete dataset we established four virtual sample points within the megaplot, each located 25 meters from the edge. At each of these sample points we identified which trees would be counted in fixed- and variable-radius plots of different sizes. We then computed the average canopy fuel characteristic across the four sample points for each plot size. The results are summarized below. The results for a one-tenth-acre fixed-radius plot are shown in bold for emphasis. Plot sizes are listed in descending order of “size”; plots at the top sample a larger number of trees than plots at the bottom.

[15] Elizabeth Reinhardt is a research Forester at the Missoula Fire Sciences Lab. Elizabeth has led or participated in the development of several fuel, fire behavior and fire effects modeling systems, including FOFEM, FFE-FVS, NEXUS, and FuelCalc.

Table 1 -- Mean canopy characteristics (n = 4) for various plot types and plot sizes. The highlighted row indicates the plot type and size recommended by the developers of FuelCalc.

Fixed-radius Plots							
Plot Id	**CBD (kg/m3)**	**CFL (t/ac)**	**CBH (ft)**	**SH (ft)**	**CC (percent)**	**Basal Area (ft2/ac)**	**Trees Per Acre**
0.50 ac	0.054	3.0	22	86	38	102	278
0.25 ac	0.058	2.9	23	85	38	110	239
0.20 ac	0.058	2.8	23	85	38	105	253
0.10 ac	**0.065**	**3.1**	**22**	**83**	**39**	**109**	**298**
0.05 ac	0.086	4.0	29	85	46	143	310
0.02 ac	0.099	4.2	42	85	53	173	183
0.01 ac	0.148	6.2	38	72	58	239	233
Variable-radius Plots							
	CBD (kg/m3)	**CFL (t/ac)**	**CBH (ft)**	**SH (ft)**	**CC (percent)**	**Basal Area (ft2/ac)**	**Trees Per Acre**
BAF10	0.065	2.9	39	87	37	115	110
BAF20	0.088	3.7	38	84	45	135	151
BAF30	0.104	4.3	37	85	49	157	150
BAF40	0.110	5.0	37	86	56	190	207
BAF50	0.109	4.8	38	85	51	175	170
BAF60	0.130	5.7	38	86	57	210	204

Plot size appears to matter significantly for the fixed-radius plots—CBD ranged from 0.054 kg/m3 for the half-acre plots to 0.148 kg/m3 for the hundredth-acre plots, a factor of three difference (for the very same plot centers). These averages mask the increasing variability as plot size decreased—CBD at the four half-acre plots ranged from 0.046 to 0.065 kg/m3, whereas the hundredth-acre plots ranged from 0.000 to 0.366 kg/m3. This situation resulted in increasing CBD values with decreasing plot size, but that is unlikely to be a universal truth. In fact, one of the four plots was located such that many trees were found on the hundredth-acre plot, whereas the others had few or none.

The variable radius plots did not tend to underestimate CBD compared to the fixed-radius plot, an unexpected result. In fact, the BAF10 (variable-radius plot with 10-factor prism), a common BAF used in vegetation sampling, produced an estimate of CBD similar to the tenth-acre plot. In fact, larger BAFs, which sample fewer trees but puts more weight on each, tended to increase the estimated CBD. While very encouraging, this result applies to this one even-aged stand; a similar result may not be found for more complex fuel structures.

Canopy fuel load, canopy cover, and stand height estimated from variable-radius plots was also similar to the fixed-radius plots.

Canopy base height estimates differed significantly between the fixed-radius plots and the variable-radius plots, which predicted much greater CBH. This is likely due to the fact that the variable-radius plots do not adequately sample small trees, so tend to under-predict biomass in the lower part of the canopy. This effect would be even greater in more complex stand structures than present in this analysis. A hybrid plot with both variable- and fixed-radius plot elements could mitigate this effect.

Finally, the variable-radius plots underestimated tree stem density relative to the fixed-radius plots, again due to the under-sampling of small trees.

In summary, this analysis supports the conclusion that variable-radius plots under-sample small trees. That is, in fact, the purpose of that plot design. For this even-aged stand, the under-sampling of small trees led to underestimation of CBH, but not CBD, CFL, or SH. Only a more exhaustive analysis with other stand structures will confirm or refute this result.

Canopy fuel calculation programs

LANDFIRE used a customized-prototype version of FuelCalc coded by Larry Gangi[16] to estimate CBD and CBH. Other fuel analysts have used the Fire and Fuels Extension to FVS or Fuels Management Analyst Plus for making the same estimates. The canopy fuel calculations in FuelCalc and FFE-FVS[17] were designed by Elizabeth Reinhardt, and FMAplus was also patterned after those programs. All three programs use the same general approach to estimating CBH and CBD, but there are slight differences in the equations used in each tool, and slight differences in certain parameters and internal models. For example, the user has control over whether any of the biomass of broadleaf tree species is factored into the CBD and CBH estimates. In theory, differences in output generated from these three programs should be small.

As a quick test of this assumption, Charley Martin's dataset of 700 FIREMON[18] plots was run through both FuelCalc and FMAplus. The resulting differences between the programs were larger than expected—FMAplus consistently over-predicted relative to FuelCalc (Figure 4).

[16] Larry Gangi is a computer programmer with Systems for Environmental Management. Larry has also served as software developer for the FOFEM and FireMon software tools.
[17] FFE-FVS is software to simulate vegetation growth and quantify fuel characteristics over time. Available at www.fs.fed.us/fmsc/fvs/description/ffe-fvs.shtml.
[18] FIREMON is software to catalog and monitor fuel and vegetation characteristics. Available at www.fire.org

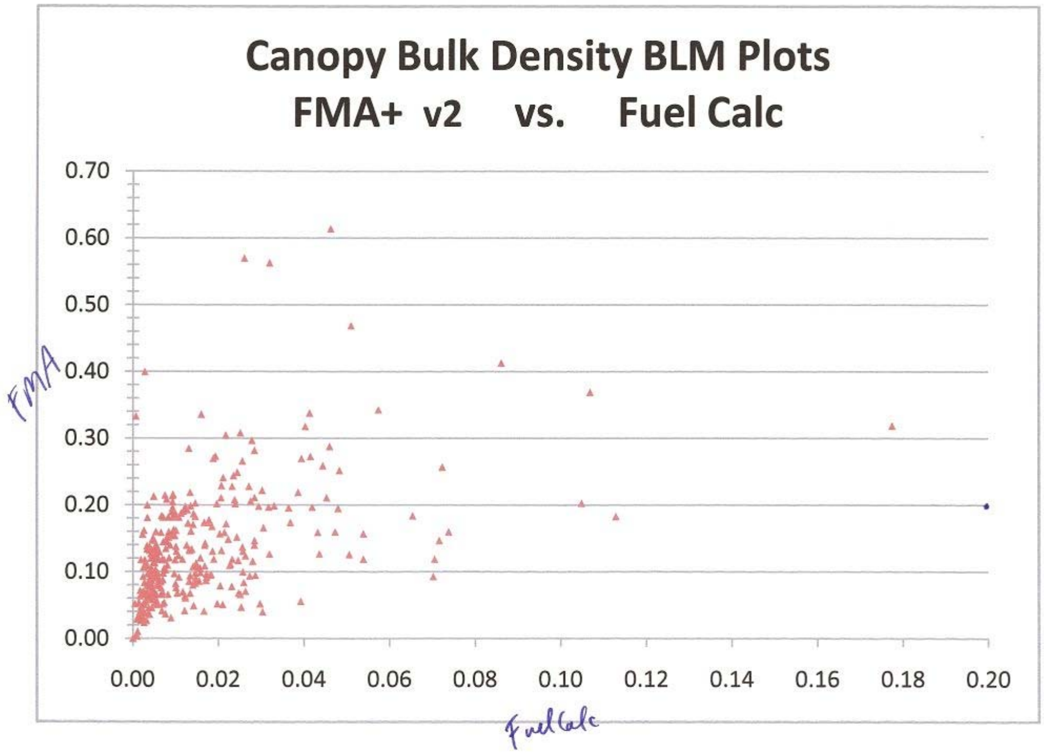

Figure 4 -- Predicted CBD (kg/m3) for FMAplus (Y-axis) and FuelCalc (X-axis). FMAplus overpredicts relative to FuelCalc, but it is not possible to know which is closest to "observed".

It is impossible at this point to know which is more accurate or reliable, but the FMAplus CBD values did not seem unreasonably high. (I don't have enough experience with the vegetation and fire behavior in the study area to confirm that conclusion, though.) It is possible that FMAplus is over-emphasizing the contribution of broadleaf species to canopy bulk density, or that FuelCalc is under-emphasizing those species.

I have forwarded this finding to Elizabeth Reinhardt, lead developer of FuelCalc, for further investigation. At this point I surmise that the FuelCalc-FMAplus comparisons were not apples-to-apples; user settings controlling different aspects of the calculation may not have been equal. FuelCalc remains the standard government application for quantifying canopy bulk density; LANDFIRE can rely on its output in mapping efforts.

The fuel and fire behavior modeling community should investigate this issue by thoroughly analyzing the outputs from a common set of treelist inputs for a variety of calculation tools. Any differences in output should be explained, and recommendations for resolving differences among the various programs should be provided.

Refreshing and calibrating LANDFIRE data

Two important limitations result from LANDFIRE's national extent: early date of validity (*ca*. 1999), and poor project-level accuracy for some fire planning applications. Refreshing data to the current year is a critical task before applying LANDFIRE's spatial data for any analysis, whether national-, regional- or project-level in extent. Improving local-level accuracy is important for project-level planning, but is not required (and may in fact hinder) regional- and national-level analyses by mixing adjusted and unadjusted data. LANDFIRE and others are addressing these issues by publishing procedures for calibrating and adjusting LANDFIRE data using a variety of *ad hoc* software tools.

To address the first limitation, LANDFIRE has developed a data-refresh plan to reflect landscape changes due to fire biennially. To jump-start the process, NIFTT[19] has conducted and nearly completed a Rapid Refresh of LANDFIRE data—a first-cut refreshing of LANDFIRE data to reflect landscape changes between 1999 and 2007. The products of this effort are expected to be replaced by a more thorough refreshing on a two-year cycle. In addition, the entire LANDFIRE mapping process will be repeated on a 10-year cycle. This procedure should ensure that high quality, up-to-date landscape data is always available. See the LANDFIRE Operations and Maintenance Business Case and Plan at http://www.landfire.gov/documents_updatedprod.php for more information.

Two separate efforts are underway to address the adjustment of LANDFIRE data to meet the needs of project-level analysis. One effort, co-funded by FPA and the National Park Service, is being carried out by Rick Stratton of Systems for Environmental Management. The product of that effort will be a document describing a process for critiquing and adjusting LANDFIRE data. A draft of this document will be available soon.

Second, NIFTT is continuing development and training of software tools and developing a training package designed to help users to download and prepare LANDFIRE. Two tutorials are available, and a course is being developed.

The DataPrep tutorial shows users how to prepare LANDFIRE data for use in NIFTT tools. This tutorial does not address adjustment or calibration of spatial data; it simply instructs users on how to download, clip, and re-project LANDFIRE data for use in a project-level analysis.

The LANDFIRE Data Access Tool tutorial describes the use of this tool for obtaining LANDFIRE data. This tutorial also does not address calibration and adjustment of the data itself.

[19] NIFTT is the National Interagency Fuel Technology Transfer team, co-funded by LANDFIRE and the National Interagency Fuel Coordination Group.

Finally, a course titled “GIS Tools for Wildland Fire and Fuels Planning” is under development. The course will teach students to download and edit LANDFIRE data for use in NIFTT’s GIS tools.

The combination of the NIFTT courses and tutorials and Stratton’s NPS/FPA-funded process for critiquing and editing LANDFIRE data should be enough guidance for most users.

Discussion

At times during their development process, LANDFIRE faced the choice of producing data that was consistent with biological science (for example, producing CBD values based on methods derived from the biomass literature) or producing data specifically adjusted so that could be consumed by a fire behavior modeling tool (CBD values manipulated so they work better in FARSITE). The LANDFIRE philosophy for the current effort was to base all data maps on the best available biological science, knowing that adjustment would be required for certain models. This is the only scientifically supportable approach. Should LANDFIRE's best biological estimate of a certain quantity end up not working well in a fire model, a quick investigation would indicate whether the problem was with the data, with the model, or with the fire modeling science. LANDFIRE should take steps to adjust any data layers it produces that are not consistent with scientifically valid field data, as they did for canopy cover values. In other cases, the fuel and fire modeling community may need to make accommodations in their fire models for the biologically estimated data.

Although users may need to critique and calibrate LANDFIRE data for use in project-level analysis, the goal of producing a nationally-consistent dataset is met without such effort. The scope of a critique and editing effort should be tied to the extent of analysis to be conducted. A national-level analysis would require a nationally consistent critique and calibration effort – LANDFIRE has already accomplished this task. A mid-scale analysis (state or region, for example) should have a critique and calibrate effort at the same scale, or none at all – mixing base LANDFIRE data for some areas with critiqued and calibrated data for others may lead to spurious results.

LANDFIRE's success at producing biologically based fuel and vegetation maps has created a situation where fire modeling difficulties can be addressed by the fire modeling community. Before LANDFIRE, without consistently created maps, fire modeling errors were always attributed to problems with the data, with no consideration for problems with the model. Geospatial fire modeling systems have been developed with a very rigid fire behavior model—no way to accommodate model error. (FARSITE has model-side spread rate adjustment factors, but other geospatial fire modeling tools do not). As a result, calibration of the fire model has always focused on changing the underlying data. When based on reliable fuel maps and weather data, many FARSITE simulations under-predict fire growth and behavior. The approach to improve simulation accuracy has been to adjust the data: reduce canopy base height, increase canopy bulk density, increase wind speed, etc. Unless there is specific evidence of a data accuracy problem, adjusting the data to suit the model is not the best approach to calibration. Instead, the fire modeling community should focus on adjusting parameters in the fire model itself. Few such adjustment factors currently exist in geospatial fire models, especially the emerging FSPro and FSIM.

Conclusion

LANDFIRE has done an admirable job integrating emerging fuel and fire modeling technologies into their mapping efforts. Given the large extent of the project, high inherent spatial variability of the characteristics being mapped, emerging (and sometimes contradictory) nature of the fuel and fire modeling technologies involved, and time constraints, no better map products could have been produced. More accurate, seamless maps can be produced at greater cost and smaller scale than required by LANDFIRE's mission. Most remaining problems with LANDFIRE data for local-level projects can be addressed through a process of calibration and adjustment. Both FPA and LANDFIRE are funding the development of procedures for accomplishing that task.

Two significant problems can potentially be addressed by LANDFIRE. First, LANDFIRE can explore whether the new canopy cover estimation techniques developed for recently placed FIA plots can be used to generate a LANDFIRE-produced forest canopy cover map to replace the inherited NLCD maps. The adjustment of this map will significantly improve fire modeling by facilitating better estimates of wind adjustment and dead fuel moisture, both of which depend on forest canopy cover. Second, in an effort to reduce data discontinuities caused by seamlines, LANDFIRE can consider strip-based mapping for any future efforts (as opposed to the present zone-base). LANDFIRE mapping for Alaska is already planning to use strip-based approach, and will serve as a good test of that approach.

References cited

Agee, J. K. 1996. The influence of forest structure on fire behavior. In: Proceedings of the 17th Annual Forest Vegetation Management Conference; 1996 January 16-18; Redding, CA. 52-68.

Cruz, M. G., M. E. Alexander and R. H. Wakimoto. 2004. Modeling the likelihood of crown fire occurrence in conifer forest stands. Forest Science 50(4): 640-658.

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

Forestry Canada Fire Danger Group. 1992. Development and structure of the Canadian Forest Fire Behavior Prediction System. Inf. Rep. ST-X-3. 63 p.

Scott, J. H. 2006. Comparison of crown fire modeling systems used in three fire management applications. Res. Pap. RMRS-RP-58. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 25 p.

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

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

Scott, J. H. and E. D. Reinhardt. 2007. FireWords Version 1.0.2: Fire Science Glossary [electronic]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/fmi

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