Wildland Fire Potential: A Tool for Assessing Wildfire Risk and Fuels Management Needs

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Abstract—*Federal wildfire managers often want to know, over large landscapes, where wildfires are likely to occur and how intense they may be. To meet this need we developed a map that we call wildland fire potential (WFP)—a raster geospatial product that can help to inform evaluations of wildfire risk or prioritization of fuels management needs across very large spatial scales (millions of acres). Our specific objective with the WFP map was to depict the relative potential for wildfire that would be difficult for suppression resources to contain. To create the 2012 version, we built upon spatial estimates of wildfire likelihood and intensity generated in 2012 with the Large Fire Simulation system (FSim) for the national interagency Fire Program Analysis system (FPA), as well as spatial fuels and vegetation data from LANDFIRE 2008 and point locations of fire occurrence from FPA (ca. 1992 – 2010). With these datasets as inputs, we produced an index of WFP for all of the conterminous United States at 885 ft (270 m) resolution. We present the final WFP map in two forms: 1) continuous integer values, and 2) five WFP classes of very low, low, moderate, high, and very high. On its own, WFP is not an explicit map of wildfire threat or risk, but when paired with spatial data depicting highly valued resources and assets such as structures or powerlines, it can approximate relative wildfire risk to those specific resources and assets. WFP is also not a forecast or wildfire outlook for any particular season, as it does not include any information on current or forecasted weather or fuel moisture conditions. It is instead intended for long-term strategic fuels management, and we provide an example of its use within the U.S. Forest Service to date.*

Introduction

Risk analysis for wildland fire management has become the subject of much research in recent years (Miller and Ager 2013). Both fire managers and policy makers increasingly want tools and information to project when and where wildfires are likely to burn, and what the potential consequences of those wildfires may be. The fundamental components involved in evaluating wildfire risk include: 1) identifying the *likelihood* (probability) of fire, 2) describing the possible *intensity* of fire should it occur, and 3) based on specific resources and assets that may be affected by fire, identifying the *effects* (positive or negative) of fire on those resources (Miller and Ager 2013, Scott and others 2013). Simply put, how likely is a place to burn; if it does burn, how likely is it to burn at certain intensities; and if there are things we care about at that place, how susceptible are they to damage (or benefit) from fire at each intensity level? Scott and others (2013) lay out a framework for wildfire risk assessment, and conceptualize the three components of risk as the wildfire risk triangle (figure 1). Their risk assessment framework has been developed and applied at various spatial scales (Calkin and others 2010; Scott and others 2013; Thompson and others 2013a; Thompson and others 2013b), and represents the current paradigm for consistent and scalable wildfire risk assessments on US public lands (Calkin and others 2011).

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

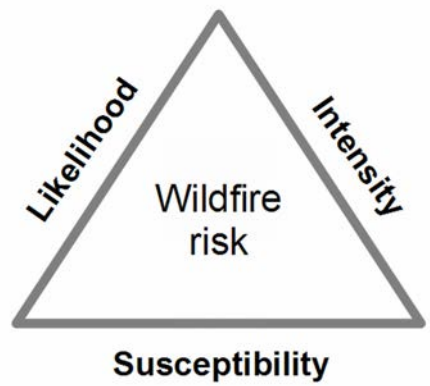

Figure 1—The wildfire risk triangle composed of the three fundamental components of wildfire risk – likelihood and intensity of fire, and the susceptibility of particular resources or assets to fire. From Scott and others 2013.

One tool developed to address the questions of likelihood and intensity is the Large Fire Simulation system (FSim) created for the national interagency Fire Program Analysis (FPA) system (Finney and others 2011). FSim was developed to produce estimates of the probabilistic components of wildfire risk, and produces spatial surfaces of burn probability and the conditional probabilities of six fire intensity levels defined by flame length classes (0 to 2 ft, 2 to 4 ft, 4 to 6 ft, 6 to 8 ft, 8 to 12 ft, and greater than 12 ft). For FPA, these spatial FSim products are output for all lands in the United States, including Alaska, Hawaii, and Puerto Rico, and are based on a number of input data sources including

spatial fuels data from the LANDFIRE project (Rollins 2009), and historic weather station and fire occurrence data from recent decades. Together, estimates of likelihood and intensity from FSim can be used to characterize the *integrated wildfire hazard*, or potential for fire to cause harm to (or produce benefits for) particular resources and assets (Scott and others 2013).

While the measure of hazard that can be obtained from FSim products is useful on its own, it does not take into consideration the third leg of the wildfire risk triangle: susceptibility. Typically in a risk assessment, this third component is captured by defining and spatially mapping a set of highly valued resources and assets (HVRAs), and conceptually outlining the percent of net value change (positive or negative) each HVRA would experience with fire at defined intensity levels. HVRAs are the things on the ground that we care about; they may be either positively or negatively affected by fire, and include facilities and infrastructure, wildland urban interface (WUI) areas, municipal water supplies, and habitat and ecosystem characteristics. The estimates of net value change for each HVRA define a response function (figure 2) that can be used in the calculation of wildfire risk to that HVRA (Scott and others 2013). The process of defining and mapping HVRAs and developing a response function for each, however, can be time consuming, complex, and costly, particularly for assessments covering a large geographic area with a diversity of fire ecology and land management concerns.

In the absence of wildfire response functions for specific HVRAs, wildfire management organizations still require information on the relative degree of suppression difficulty at any location across the landscape to aid in identifying fire management and risk mitigation opportunities and challenges. Therefore, our objective was to produce a spatial index of the relative potential for wildfire that would be difficult for suppression resources to contain. An extension of the integrated wildfire hazard concept, we call this index Wildland Fire Potential (WFP). Areas mapped with higher WFP values represent fuels and other landscape conditions with a higher probability of experiencing high-intensity fire with torching, crowning, and other forms of extreme wildfire behavior under conducive weather conditions. We chose to produce the WFP map for all lands in the conterminous United States (CONUS). In lieu of a full national-scale risk assessment (which is currently in progress), the WFP map provides a strategic CONUS-wide tool for identifying and prioritizing areas most in need of fuel treatments to reduce potential fire intensities. Further, in conjunction with other spatial data depicting particular HVRAs such as residential communities or watersheds important for municipal drinking water, prioritization with the WFP map can be narrowed to areas meeting particular fire and land management objectives.

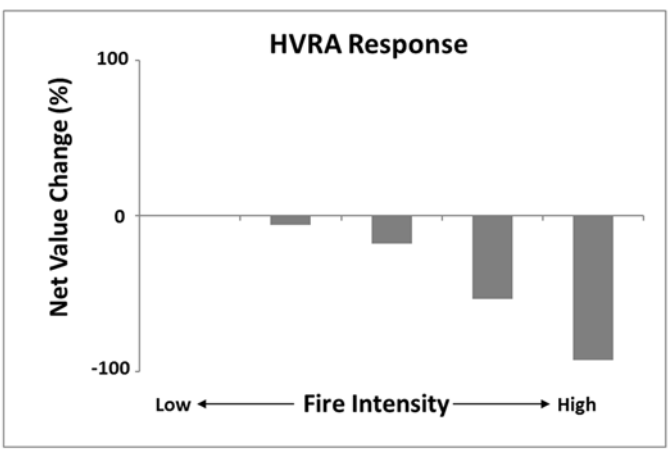

Figure 2—A wildfire response function illustrating the estimated net value change for a particular highly valued resource or asset (HVRA) with different fire intensity levels. In this example, fire negatively impacts the HVRA at all flame lengths, with the impact increasing with flame length.

This current effort builds upon previous iterations of the WFP map produced in 2007 (Menakis 2008) and 2010, but differs significantly from those earlier products. Considerable improvements in input data sources and wildfire simulation modeling methods, refinements to the 2010 WFP mapping methods, and a general evolution in wildfire risk assessment concepts have all occurred since 2010. This paper focuses primarily on the methods used to generate the 2012 WFP map, with an example of how it is being used within the USDA Forest Service to aid in prioritizing national-scale fuels management needs.

Methods

To develop our map of WFP, we integrated CONUS FSim modeling outputs generated for FPA in 2012 (FPA and USFS 2012), point fire occurrence records from 1992-2010 (Short 2014), and spatial vegetation and fuels data from the LANDFIRE project (Rollins 2009) (figure 3). The process can be summarized by five main stages: 1) calculate a large wildfire potential using the FPA FSim products and weighting different intensity levels according to the difficulty they pose to suppression efforts; 2) create a separate surface of small wildfire potential based on ignition locations for fires smaller than 300 acres (which are not the focus of FSim modeling); 3) integrate the large wildfire potential and the small wildfire potential; 4) apply a set of resistance to control weights based on fireline construction rates in different fuel types; and 5) produce the final WFP products.

Calculate the Large Wildfire Potential

This first step in the process of mapping WFP is to integrate the FSim burn probability (figure 4) and conditional probabilities for flame length classes (figure 5). The CONUS FSim products are 885 ft (270 m) raster mosaics from wildfire simulations performed individually in 132 Fire Planning Units (FPUs) across the country, and provide the foundation for the WFP map. In each FPU, daily ignitions and fire spread are modeled over at least 20,000 contemporary fire seasons (in other words, not future projections), given statistically possible weather conditions based on observations from recent decades (Finney and others 2011). At the

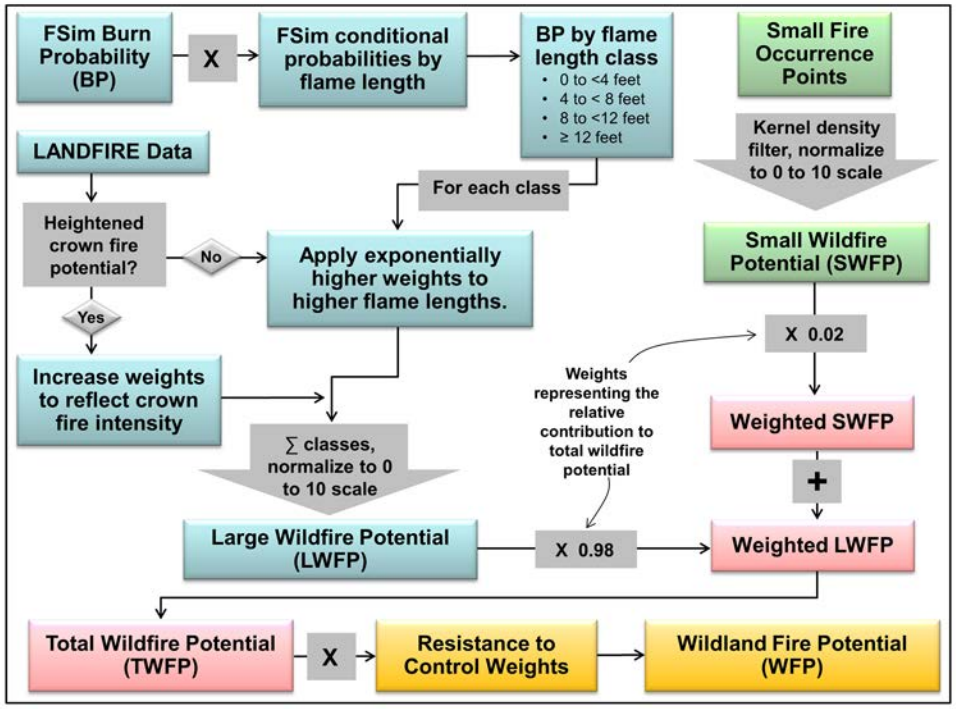

Figure 3—Generalized flowchart of the WFP mapping process. Creation of the Large Wildfire Potential layer is in blue; creation of the Small Wildfire Potential layer is in green; integration of the two is in pink; and the application of resistance to control weights and final processing to create the WFP product are in orange.

end of a simulation run, the number of times a given pixel burned is divided by the total number of simulation years to get the pixel-level burn probability (for example, 200 times in 20,000 runs yields a probability of 0.01). The proportion of times that a pixel burned in a particular flame length class provides the conditional flame length probability (for example, if out of the 200 times the pixel burned, 150 were with 8 to12 foot flames, then the conditional probability for that flame length class is 0.75). FSim outputs conditional probabilities for six classes of flame length, but we aggregated the data into four classes: 0 to < 4 ft, 4 to < 8 ft, 8 to < 12 ft, and ≥ 12 ft. By multiplying the overall burn probability by the conditional probability for each of our four flame length classes we get the actual burn probability for each flame length class (figure 6).

Next, we used established mathematical relationships between flame length and fireline intensity (Andrews and others 2011), to weight the potential hazard represented by each of our four flame length classes. In a sense our weighting approach is similar to the response functions used in risk assessments, although here we are not focusing on the relative susceptibility of a resource or asset but rather variable levels of suppression difficulty. To develop our weighting scheme, we followed the logic that as flame lengths (and fireline intensities) increase, fires become increasingly difficult to control. This logic has long been recognized by fire scientists and fire managers alike, and is represented in the surface fire behavior fire characteristics chart, also known as the "hauling chart" (Andrews and Rothermel 1982). Using the lowest flame length class (0 to <4 ft) as our baseline, along with an equation for surface fireline intensity (Byram 1959), we derived weights by simply determining how much greater the average fireline intensity is in each of our flame length classes compared to the baseline (table 1).

While FSim modeling does incorporate crown fire to the extent possible with our current modeling capabilities, the conditional flame length probabilities represent surface fire flame lengths calculated from Byram's (1959) equation (Finney and others 2011). As a result, they likely underrepresent the actual flame lengths (heights) possible during a crown fire event (Short, personal communication). Therefore, we sought to identify places with a heightened potential for crown fire based on the vertical fuel profile and weight them accordingly as the upper end of the fire intensity spectrum (figure 2). We used spatial data from the LANDFIRE project[1] depicting forest canopy characteristics (canopy cover, canopy height, and canopy base height) to accomplish this. We first identified areas that met two basic criteria we defined for closed-canopy forest: 1) forest canopy height > 16 ft (5 m); and 2) forest canopy cover > 50 percent. Next, we evaluated each of the original FSim flame length classes above 4 ft with the following criteria: 1) conditional probability for the flame length class is greater than zero; and 2) the upper value for flame length overlaps with the canopy base height (for example, canopy base height < 6 ft and flame length of 4 to 6 ft). Evaluating these criteria on a pixel-by-pixel basis, we developed a spatial mask identifying areas with forest crown fire potential (figure 7).

Recognizing that high intensity crown fire behavior is also possible in some non-forest vegetation such as California chaparral, we used an additional set of criteria to add these pixels into our crown fire potential mask. We

[1] Because the spatial resolution of LANDFIRE data is 97 ft (30 m), and the FSim data are at 885 ft (270 m), we resampled LANDFIRE data layers up to 885 ft (270 m) resolution. LANDFIRE fuels layers were used as input to the FPA FSim runs, and they were also resampled up to 885 ft (270 m) by FPA. All LANDFIRE layers used in both the FPA FSim runs and our 2012 WFP mapping were LANDFIRE Refresh 2008 (v 1.1.0).

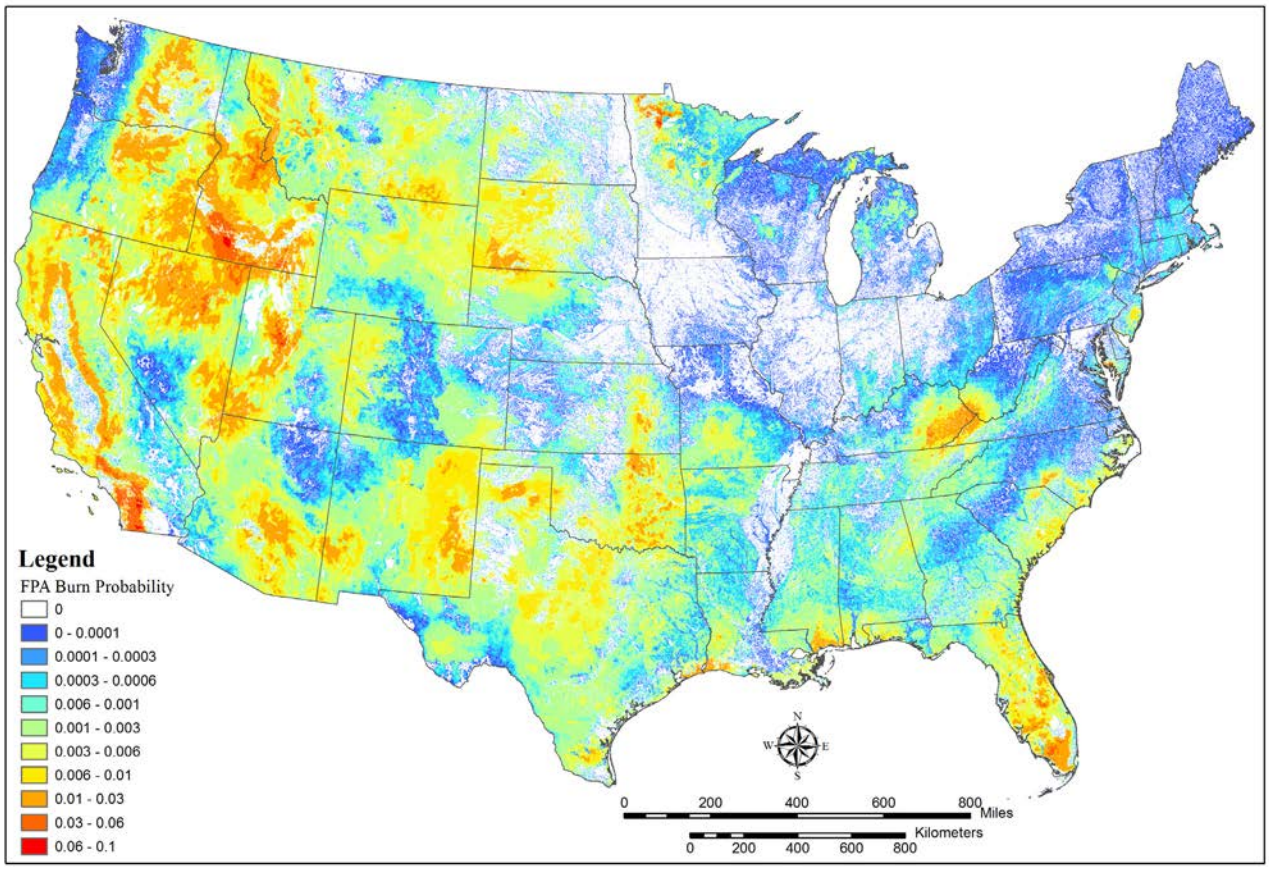

Figure 4—Annual burn probability from the Large Fire Simulator (FSim), generated for the national Fire Program Analysis (FPA) system in 2012 from LANDFIRE 2008 fuels data (FPA and USFS 2012).

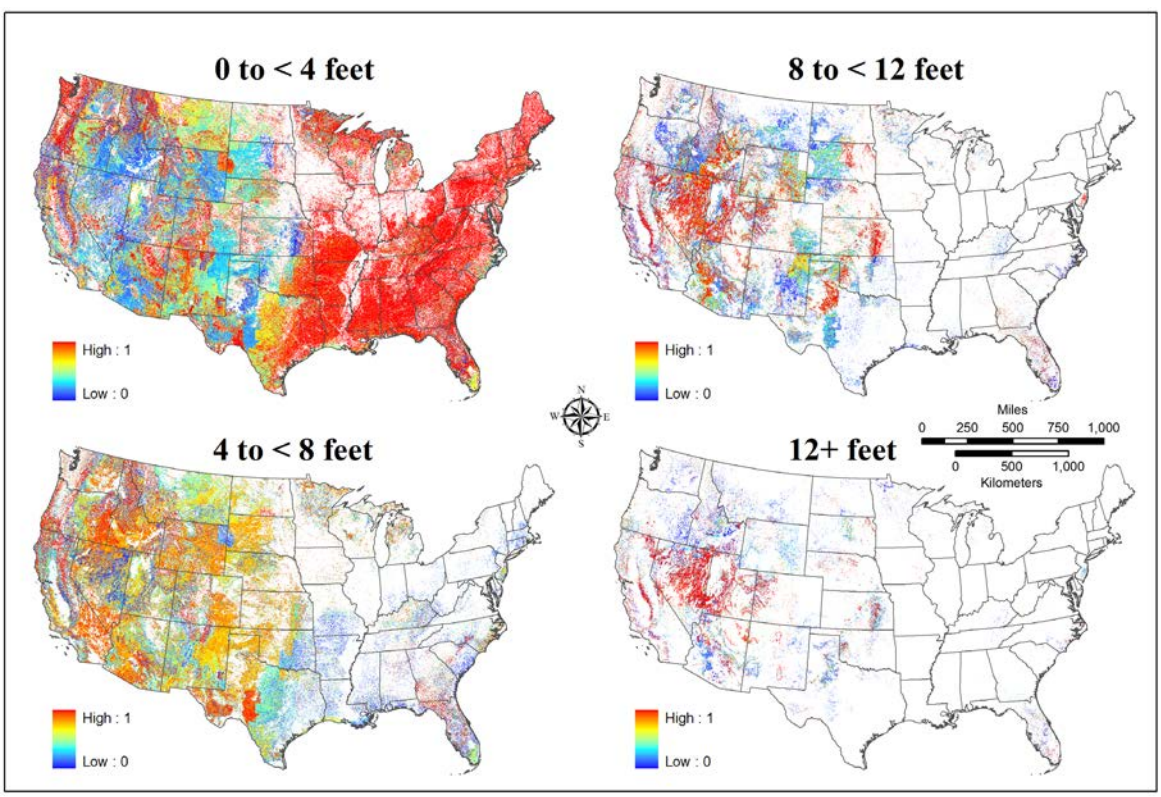

Figure 5—Conditional probability from the large fire simulator (FSim) for each of four aggregated flame length classes, generated for the national Fire Program Analysis (FPA) system in 2012 from LANDFIRE 2008 fuels data (FPA and USFS 2012).

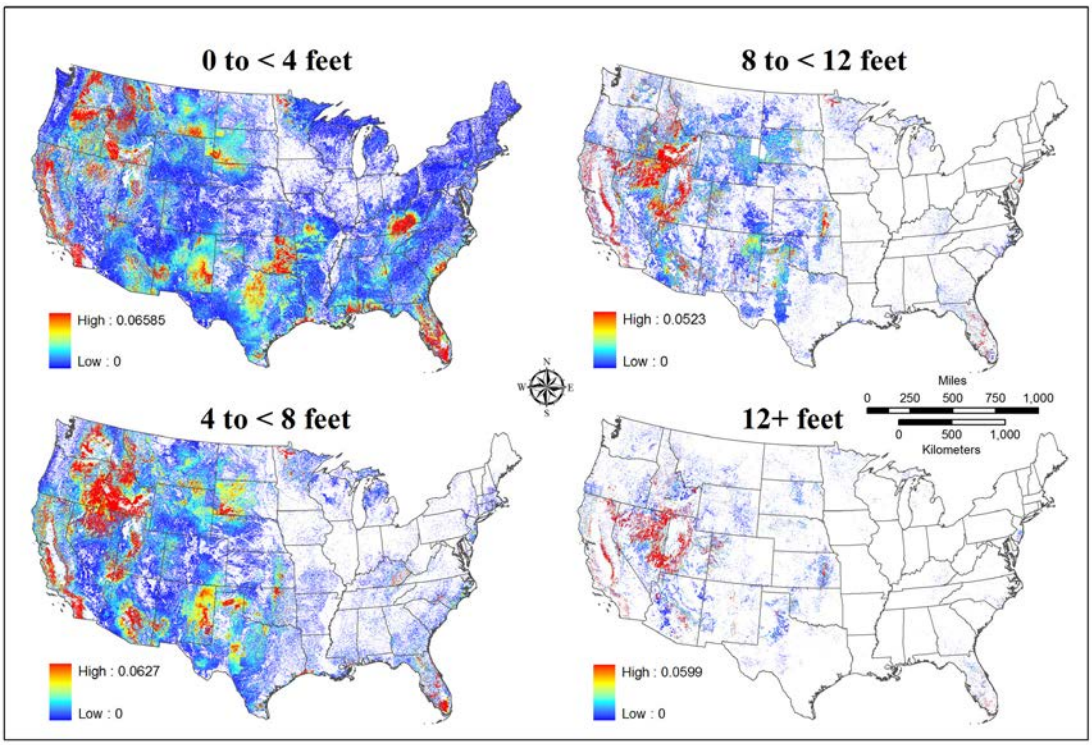

Figure 6—Burn probability for each of four aggregated flame length classes, calculated as the product of the large fire simulator (FSim) burn probability and conditional flame length probabilities (FPA and USFS 2012).

Table 1—Derivation of weights based on fireline intensities for surface fires.

Surface flame length (ft)	Fireline intesity (Btu/ft/s) [a]	Average intensity	How many "times as intense" as < 4 ft flames? [b]	Weighting used for WFP
1	5.67	31.03	1.0	1
2	25.60			
3	61.82			
4	115.53	243.03	7.8	8
5	187.67			
6	278.95			
7	389.99			
8	521.34	770.86	24.8	25
9	673.48			
10	846.84			
11	1,041.80			
12	1,258.73	2,430.67	78.3	75
13	1,497.97			
14	1,759.82			
15	2,044.59			
16	2,352.55			
17	2,683.95			
18	3,039.06			
19	3,418.10			
20	3,821.31			

[a] Calculated as: (Flame Length / 0.45)2.173913 based on Byram (1959).
[b] Calculated as: (Average intensity of current flame length class / average intensity of 0 to <4 ft flame lengths).

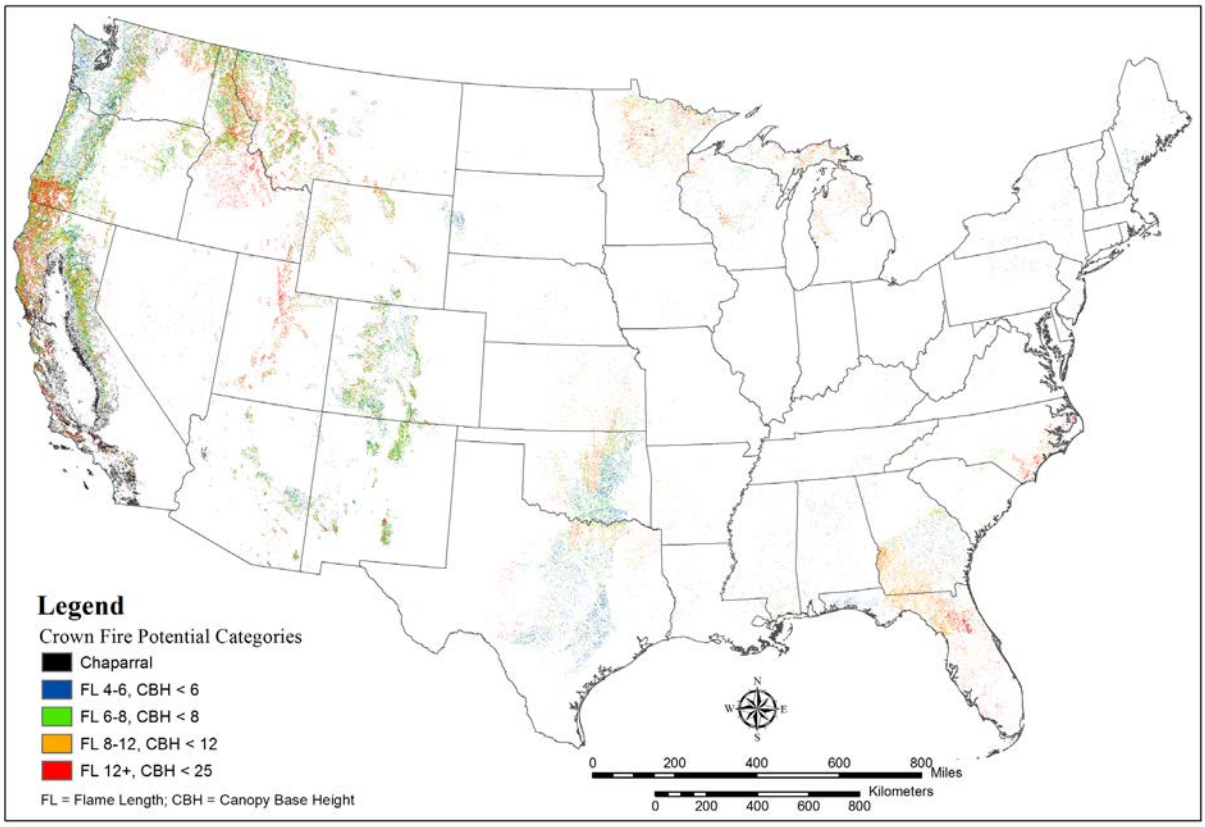

Figure 7—Map of areas meeting criteria for crown fire potential. Burn probabilities by flame length class were multiplied by the crown fire weight of 130 in all colored pixels, and by appropriate weights for surface fire flame lengths in all other areas.

identified chaparral pixels using the LANDFIRE Existing Vegetation Type layer (EVT) (table 2). Out of the chaparral EVT classes, we considered pixels with > 30 percent shrub cover in the LANDFIRE Existing Vegetation Cover layer to be capable of supporting crown fire. In addition to other criteria, Fried and others (2004) defined the highest hazard class in chaparral as having > 25 percent shrub cover; 30 percent was the closest LANDFIRE cover class break to this value.

Table 2—LANDFIRE Existing Vegetation Type (EVT) classes used to identify chaparral crown fire potential.

EVT Code	EVT Name
2096	California Maritime Chaparral
2097	California Mesic Chaparral
2098	California Montane Woodland and Chaparral
2099	California Xeric Serpentine Chaparral
2105	Northern and Central California Dry-Mesic Chaparral
2110	Southern California Dry-Mesic Chaparral
2092	Southern California Coastal Scrub
2128	Northern California Coastal Scrub
2108	Sonora-Mojave Semi-Desert Chaparral [a]

[a] Mapped in Southern California mountains and around Central Valley

To derive a weight for areas with crown fire potential, we again used established relationships between flame length and fireline intensity. Using an equation for crown fire intensity (Thomas 1963), we chose a representative range of flame lengths that could be expected under generalized crown fire conditions (20 to 80 ft) and calculated the average fireline intensity within this range. This resulted in a weight of 130 for areas where crown fire flame lengths are possible (average fireline intensity of 4,075 Btu/ft/s, approximately 130 times greater than the intensity of 0 to 4 ft surface flames).

Once we had derived weights and identified pixels with crown fire potential, we applied the weights to the burn probabilities in each of our four flame length classes. For each class, for pixels where the criteria for crown fire potential were met, we multiplied the burn probability for that class by the crown fire weight (130). For pixels where the criteria for crown fire potential were not met, we multiplied the burn probabilities by the appropriate weight for surface fire (table 1).

After applying weights to the burn probabilities in each flame length class, we summed the resulting values at each pixel to get a measure of large wildfire potential (LWFP). It is important to note that at this point in the process, we no longer have burn probabilities; instead we have a dimensionless index. The raw values range from 0 to approximately 8.8. To better align this index with the independently-derived small wildfire potential (SWFP) index, we normalized the LWFP to a scale of 0 to 10.

Calculate the Small Wildfire Potential

FSim modeling focuses on large fires because they account for over 90% of the total area burned in wildfires (Finney and others 2011; Short 2013). As such, simulated fires are more likely to grow large in areas where large fires have been more common on the landscape, based on the ignition density of fires > 50 to 300 acres since 1992. Areas that have experienced mostly smaller fires, therefore, tend to get very low burn probabilities. For the WFP, however, we wanted to reflect that areas with predominantly small fires in recent decades also represent some potential for future fires. Particularly where management strategies (for example, hazardous fuels treatment or preparedness efforts) may have been successful at limiting large fires in the past, burn probabilities based on large fires alone may underestimate the wildfire potential. Since the WFP product could be used for prioritizing locations of hazardous fuels treatments or moving preparedness crews we did not want to limit our analysis to only large fires.

To account for small fires in the WFP, we created a smoothed ignition density surface using the same method that FPA uses to create their large fire ignition density grid. Using FPA's point fire occurrence database (Short 2013), we first selected out all points representing fires with a final size < 300 acres. Next, we applied a kernel density function (Silverman 1986, equation 4.5) to the small fire points in ArcGIS, specifying a search radius of 31.07 mi (50 km) and an output raster cell size of 885 ft (270 m) to match all raster layers used for the LWFP. Values in each cell of the kernel density surface represent number of ignitions per square kilometer during the period of the database (1992-2012), averaged across a 31.07 mi (50 km)-radius area around each cell. Values ranged from 0 to 1.56. To convert this to a SWFP index, aligned with the LWFP, we normalized it to a scale of 0 to 10 (figure 8).

Calculate Total Wildfire Potential

With the LWFP and SWFP created and normalized to the same scale, we assigned each a weight to reflect the relative contribution of each to total wildfire potential (TWFP), then added the weighted values to calculate the TWFP. We tested several weights, starting with 0.5 for each, representing an equal contribution of LWFP and SWFP to TWFP. Using equal weights, however, it was obvious that the spatial patterns from the SWFP overpowered any contribution from the LWFP and we incrementally increased the weight for the LWFP until the product looked reasonable. To evaluate this, we examined the TWFP visually in ArcGIS (ESRI 2011), overlaying observed fire perimeters from recent decades (acquired from the Monitoring Trends in Burn Severity project; http://www.mtbs.gov), and comparing the relative output values between areas that experience a lot of fire and areas that have little to no fire. This process led to the final weights of 0.98 for LWFP and 0.02 for SWFP, which, despite being very lopsided, allowed for the SWFP to have a noticeable influence on the TWFP but not overpower the

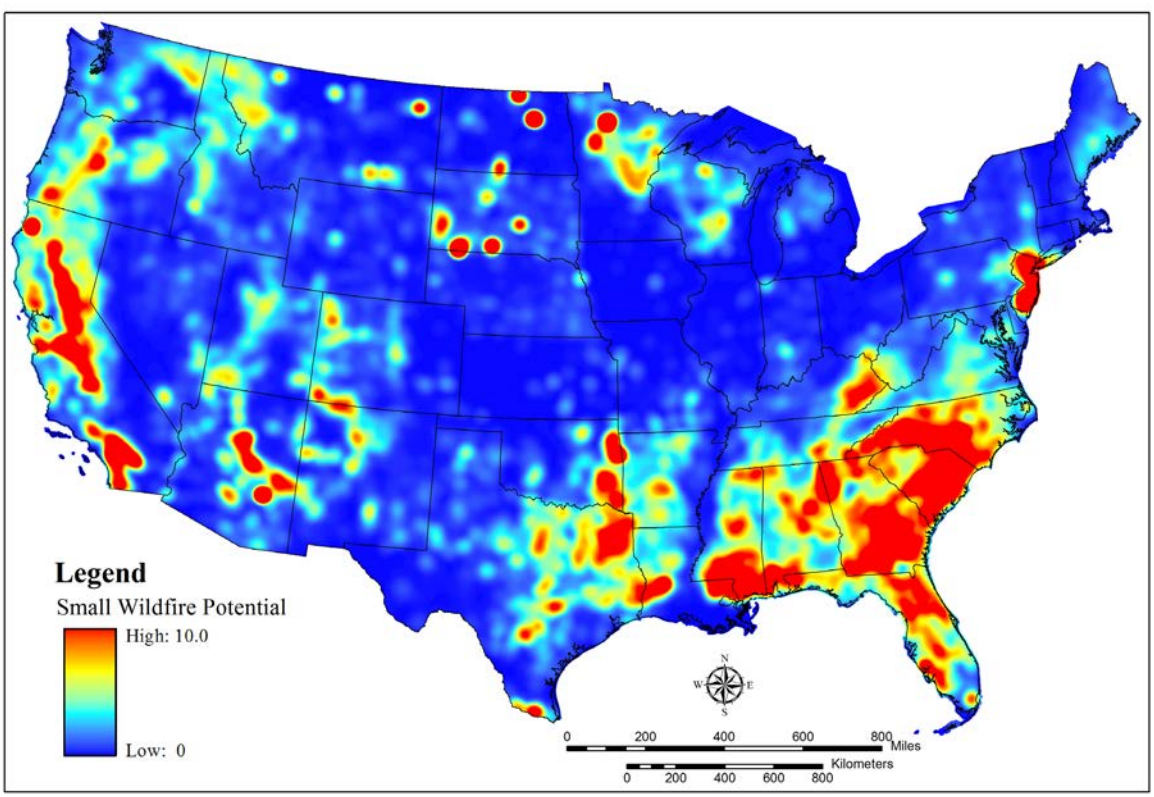

Figure 8—Map of small wildfire potential, a scaled ignition density surface for all fires less than 300 acres from 1992 to 2010. The large, rounded shapes reflect the 31.07 mi (50 km) search radius used in a kernel density function to smooth the ignition density surface.

LWFP contribution. These weights also closely approximate the relative contribution of "large" and "small" fires to total area burned.

Apply Resistance to Control Weights

Keeping in mind our objective of depicting the potential for fire that would be difficult for suppression resources to contain, we applied a final set of resistance to control (RTC) weights to the TWFP (figure 9). Based on the concept that fires are easier to contain in some fuel types than others, the fireline handbook (NWCG 2004) lists fireline production rates (ch/hr) for initial attack by hand crews for the original Anderson 13 fuel models (Anderson 1982). FPA has updated these line construction rates for the newer 40 fuel models (Scott and Burgan 2005), with the most recent update made in 2010. Using these rates to calculate an RTC weight for each of the 40 fuel models, we could then use the LANDFIRE Refresh 2008 (v1.1.0) Fire Behavior Fuel Model 40 (FBFM40) layer to apply the weights spatially to adjust the values in our TWFP layer.

To derive RTC weights from FPA's line construction rates, we first calculated the reciprocal of the rate (1/rate). This results in fuel models with a line construction rate greater than one (easier to control) getting an RTC weight less than one (table 3). When the TWFP is multiplied by these RTC weights, the index of potential in the final WFP output is therefore reduced. Conversely, fuel models with a line construction rate greater than one (harder to control) would get an RTC weight greater than one, resulting in increased WFP. After applying RTC weights based solely on this logic, however, we found that the effect on the final WFP index, particularly in fuel models with RTC weights greater than one, was too much. It was essentially giving the LANDFIRE FBFM40 too much influence on the final WFP product.

To refine the RTC weights, we made some adjustments to the weights themselves and to the way we applied them spatially. Since our main goal with these weights was to reduce the WFP values in fuel models with a higher likelihood of suppression success (for example, light grasses and shrubs, hardwood litter), we decided to only apply RTC weights that are less than one. In four timber understory and litter fuel models, we also manually adjusted the RTC weight up to one (table 3) based on our visual examinations of initial tests in ArcGIS. Lastly, to guard against potential mapping errors in the FBFM40, we incorporated the LANDFIRE EVT when applying the weights spatially. Anywhere with a conifer EVT class, we automatically set the RTC weight to one.

Produce the Final WFP Products

The product that results from the process steps above is an 885-ft (270-m) resolution raster layer, with values representing wildland fire potential on a continuous 0 to 10 scale. We apply a few further geospatial processing steps to convert it into the two final WFP products: one with continuous

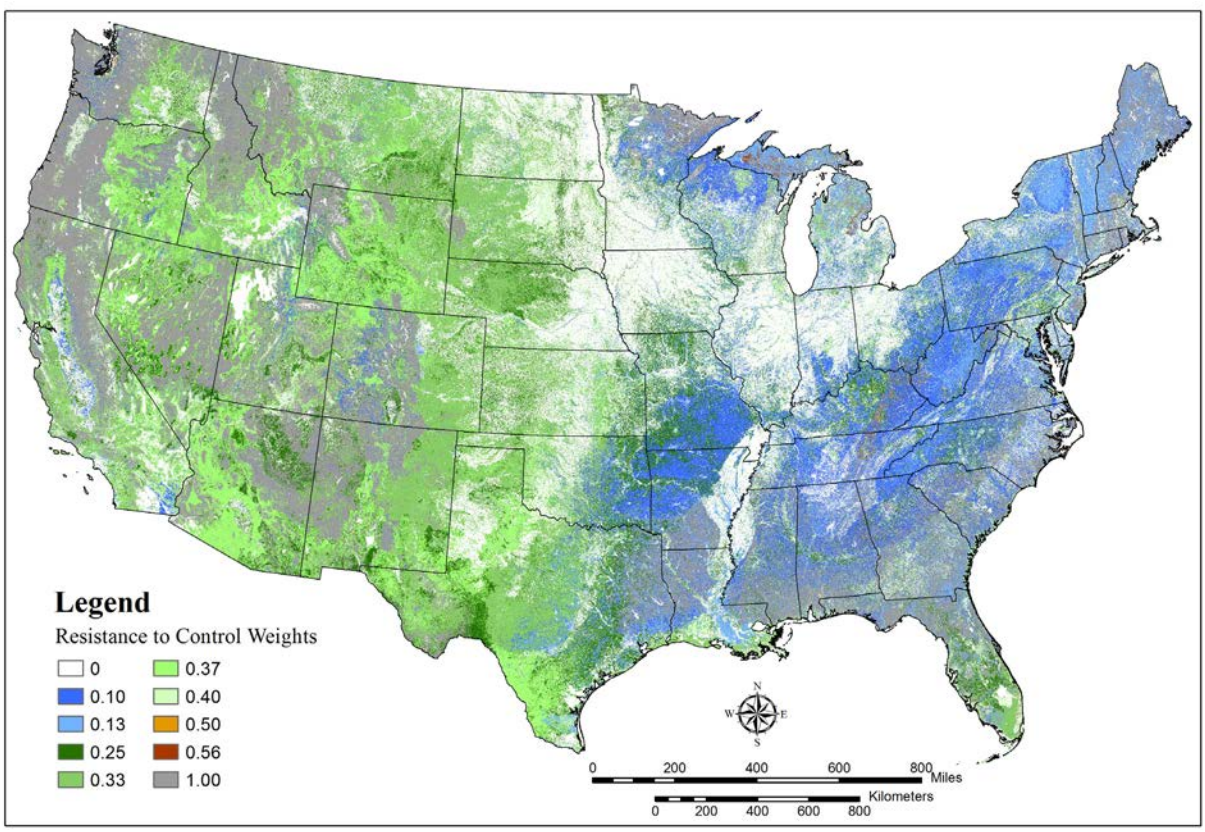

Figure 9—Map of the spatial distribution of adjusted resistance to control (RTC) weights, derived from fireline construction rates for the Scott and Burgan (2005) fuel models (see table 3).

Table 3—Resistance to control (RTC) weights for fuel models with line construction rates > 1 chain/hour.

Fuel Model	Fireline construction rate (ch/hr) [a]	Calculated RTC weight [b]	Adjusted RTC weight [c]
GR1 (101) Short, Sparse Dry Climate Grass (Grass)	4	0.25	0.25
GR2 (102) Low Load, Dry Climate Grass (Grass)	3	0.33	0.33
GR3 (103) Low Load, Very Coarse, Humid Climate Grass	2.49	0.40	0.40
GR4 (104) Moderate Load, Dry Climate Grass	2.49	0.40	0.40
GR5 (105) Low Load, Humid Climate Grass	3	0.33	0.33
GR6 (106) Moderate Load, Humid Climate Grass	2.49	0.40	0.40
GS1 (121) Low Load, Dry Climate Grass-Shrub	2.7	0.37	0.37
GS2 (122) Moderate Load, Dry Climate Grass-Shrub	2.7	0.37	0.37
GS3 (123) Moderate Load, Humid Climate Grass-Shrub	2.7	0.37	0.37
TU1 (161) Low Load Dry Climate Timber-Grass-Shrub (Hardwood)	10	0.10	0.10
TU2 (162) Moderate Load, Humid Climate Timber-Shrub	1.8	0.56	0.56
TL2 (182) Low Load Broadleaf Litter	8	0.13	0.13
TL6 (186) Moderate Load Broadleaf Litter	10	0.10	0.10
TL9 (189) Very High Load Broadleaf Litter	2	0.50	0.50
TU1 (161) Low Load Dry Climate Timber-Grass-Shrub (Conifer)	2	0.50	1.00
TL1 (181) Low Load Compact Conifer Litter	2	0.50	1.00
TL3 (183) Moderate Load Conifer Litter	1.8	0.56	1.00
TL8 (188) Long-Needle Litter	2	0.50	1.00

[a] Published by FPA 4/27/10
[b] Calculated as: (1 / Fireline construction rate)
[c] Some weights manually adjusted based on visual examination of tests in ArcGIS.

integer values on a 0 to 100,000 scale, and another that is classified into five WFP classes. To create the first of these, we multiply the original 0 to 10 floating point values by 10,000, then round to the nearest integer. This preserves four decimals of precision in the original output, but converts values to integer format, which makes the file size of the resulting raster layer much smaller and more manageable. This is the Continuous WFP product (figure 10).

We evaluated a number of ways to classify the Continuous WFP into the following five WFP classes: very low, low, moderate, high, and very high. The values in the Continuous WFP are heavily skewed toward lower values, with a long tail extending out to very high values (figure 11a). Because of this distribution, we found it helpful to visualize the distribution on a natural log scale (figure 11b), and pursue class breaks based on percentiles. Conceptually, we started with the idea that land managers have limited resources for strategic fire management efforts such as fuels treatment and positioning of suppression assets, and need to be able to focus those efforts where they are most needed. Therefore, our goal was to derive a classification that placed most of the landscape into very low, low, and moderate WFP classes and constrained the high and very high WFP classes to the upper tail of the distribution, thus highlighting the areas of greatest concern for management. We classified the Continuous WFP using a variety of percentile breaks (table 4), each time evaluating the resulting map visually in ArcGIS and tabularly with a summary of acres in each WFP class. Ultimately, we determined the following percentile breaks best met our objectives: very low to low at 44th percentile; low to moderate at 67th percentile; moderate to high at 84th percentile; high to very high at 96th percentile (table 4, trial 4). The logic behind these class breaks was:

- $^2/_3$ of total area should be in the very low or low WFP classes
  - of that, $^2/_3$ is in very low and $^1/_3$ is in low
- the remaining $^1/_3$ of total area has moderate, high, and very high WFP
  - of that, ½ is in the moderate class
  - the remaining ½ (of the upper $^1/_3$) is divided as follows:
    - $^2/_3$ is in the high class
    - $^1/_3$ is in the very high class (see inset in figure 12).

The final step in processing the Classified WFP was to add in water and other non-burnable land cover types. To do this, we used the LANDFIRE FBFM40 layer and selected the water class (NB8) and all non-burnable fuel models (NB1—urban or suburban development; NB2—snow/ice; NB3—agricultural field, maintained in non-burnable condition; and NB9—bare ground).

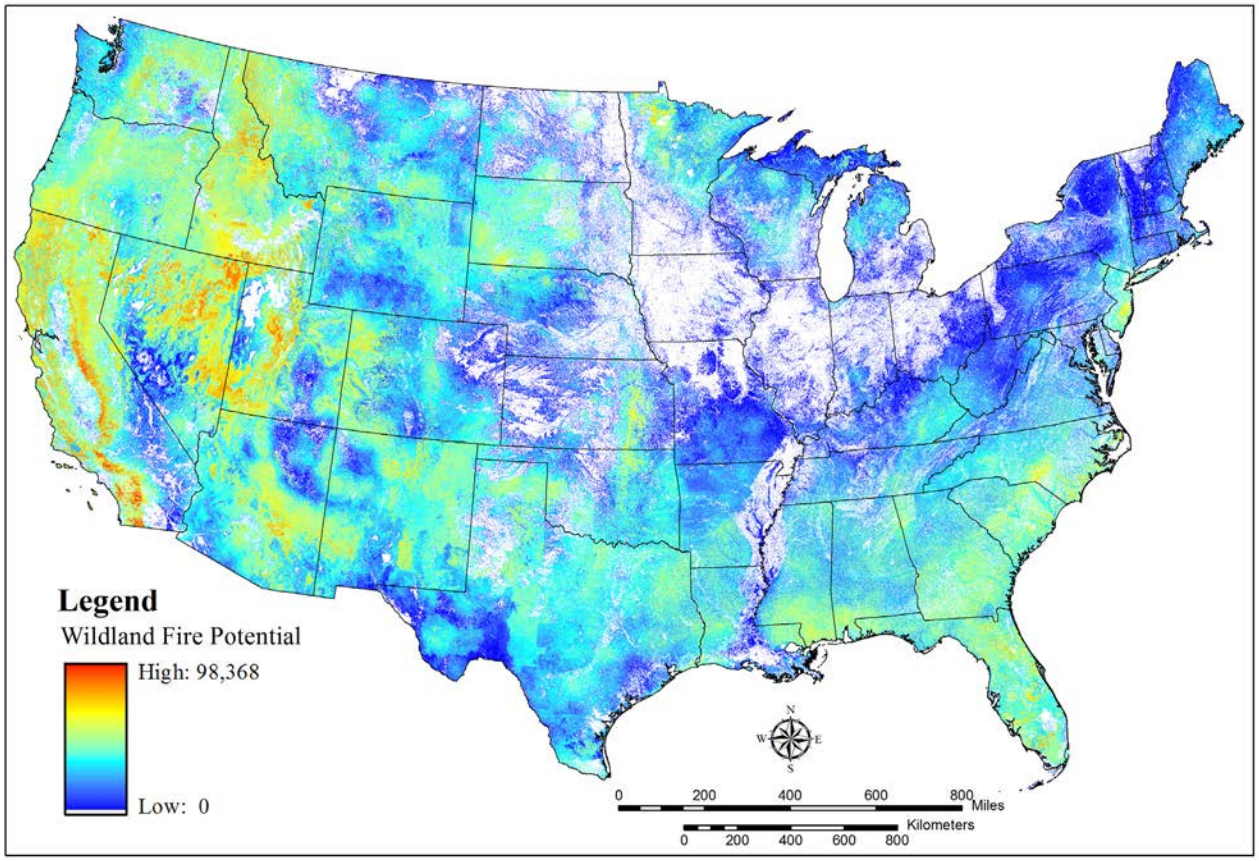

Figure 10—Map of the continuous WFP index. Values are displayed here using a 32-class geometrical interval classification (ESRI 2011) to maximize visual differentiation of values, given the strongly skewed distribution.

Data Products

The continuous WFP index has values that range from zero (primarily developed, agricultural, and unvegetated areas where the modeled burn probability was zero) to 98,368 (figure 10). The distribution of continuous WFP values is very positively skewed, with over 95 percent of values less than 2,000 (figure 11a). Spatially, the highest WFP values are most heavily concentrated in the eastern foothills of the Sierra Nevada Mountains, as well as the transverse and peninsular ranges, in California; and in the mountain ranges of northern and eastern Nevada and central and southeastern Utah. High WFP values are also scattered throughout other western states, as well as a few locations in the upper Midwest (northern Minnesota) and Southeast (Florida).

The classified WFP product provides a simplified and more interpretable view of relative wildland fire potential, with its five classes ranging from very low to very high potential (figure 12). The high and very high WFP classes, which represent the long upper tail of the continuous WFP distribution, are most abundant in the mountains of California, Nevada, Idaho, and other western states, but 22 states have a total of over 1,000,000 acres (most over 2,000,000 acres) in these two WFP classes combined (table 5). Notable areas outside the mountainous west with areas of high and very high WFP include pine forests throughout the Gulf and Atlantic Coastal Plain, the Pine Barrens in New Jersey, tallgrass prairie in the Flint Hills of Kansas, and northern boreal forests in northern Minnesota (figure 12).

Notably, the percentage of total area in each of the mapped WFP classes does not match exactly with the percentile values used to assign classes (table 6). The very high WFP class accounts for approximately 4 percent of the total (compared to an expected 5 percent, using a 95th percentile threshold), while the high and very high classes combined account for approximately 12 percent (compared to an expected 16 percent). These discrepancies are the result of adding in the non-burnable and water classes after evaluating the percentile breaks in the continuous WFP index. Additionally, the proportions of mapped area in different WFP classes on National Forest System (NFS) and Department of Interior (DOI) lands are quite different from proportions on all lands (table 6). The moderate, high, and very high classes are proportionally more abundant on NFS lands, while the very low and non-burnable classes are much more prevalent when considering all lands.

We completed development of the continuous and classified WFP products in late 2012, and made them available online in February 2013. Visitors to the WFP website (http://www.firelab.org/project/wildland-fire-potential) can download the raster geospatial data for either the

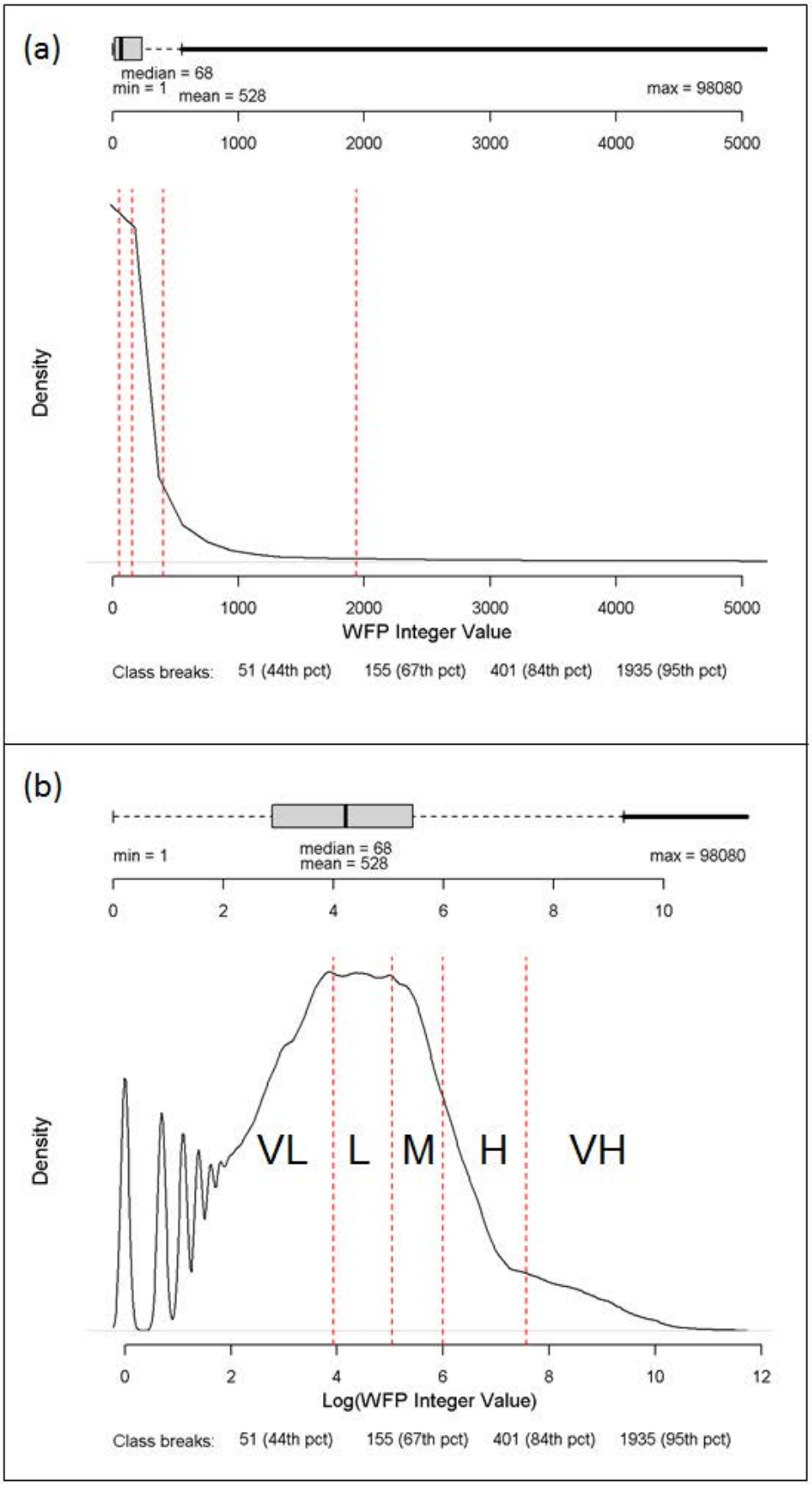

Figure 11—Boxplots and probability density curves (histograms) of continuous integer WFP values: (a) on the original measurement scale, and (b) on a natural log scale. Values in (a) are strongly skewed toward the lower end of the range, with over 95% of values less than 2,000. The upper tail in (a) is truncated at 5,000 for the purposes of this figure, but the full distribution extends to more than 98,000. Log-transformed values in (b) are much more normally-distributed. Plots shown here are from a sample of 10,000,000 pixels from the CONUS map. The shaded box in the box plots depicts the inter-quartile range and the vertical black hash mark is the median. Dashed red lines on the histograms show class breaks used in creating the classified WFP map. Integer WFP values for class breaks along with corresponding percentiles are given along the bottom.

Table 4—Different percentiles and corresponding integer WFP values tested for determining class breaks for the Classified WFP. The selected trial is highlighted.

	Very Low to Low		Low to Moderate		Moderate to High		High to Very High	
Trial	percentile	value	percentile	value	percentile	value	percentile	value
1	33	29	66	148	90	697	97	3848
2	33	29	66	148	85	433	95	1935
3	50	68	75	232	88	562	96	2658
4	44	51	67	156	84	401	95	1935
5	44	51	67	156	89	623	96	2658
6	23	16	67	156	93	1123	99	9668

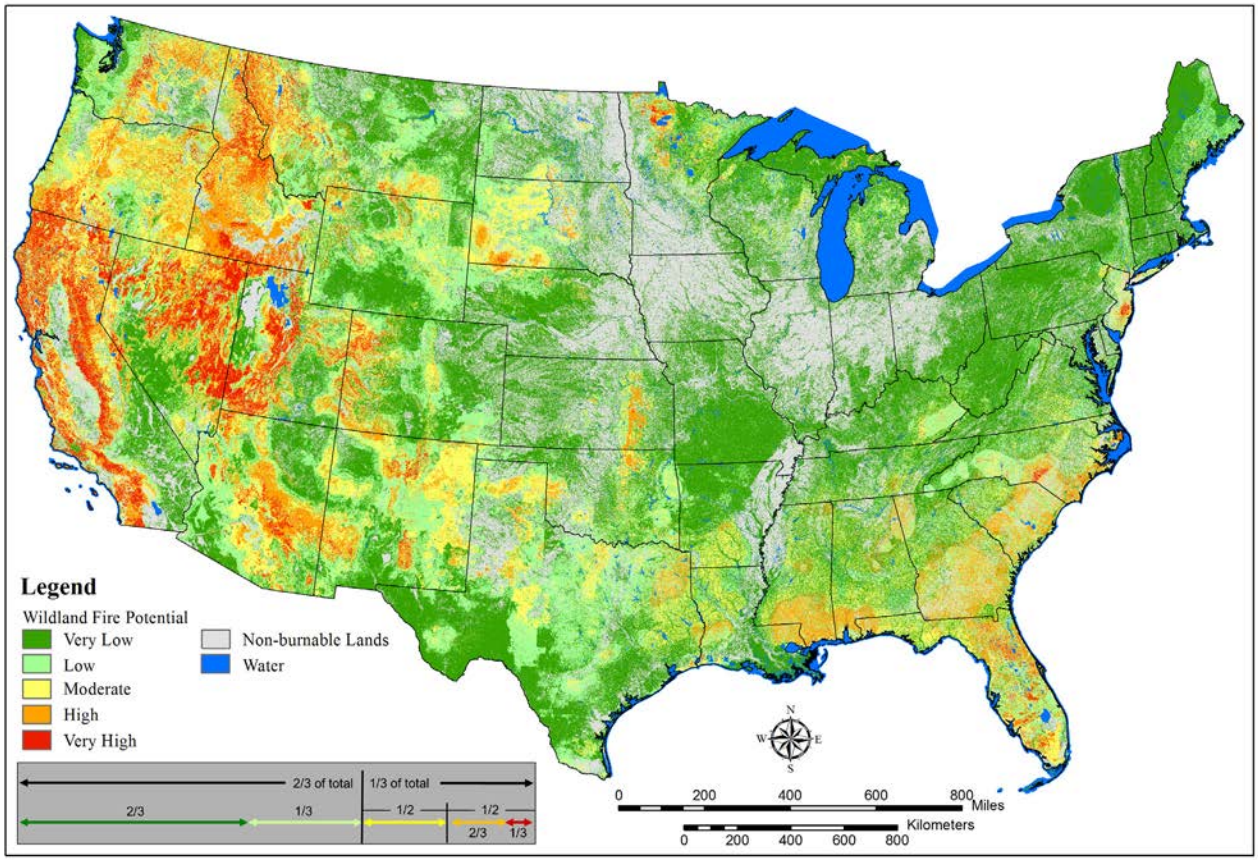

Figure 12—The classified Wildland Fire Potential map. Non-burnable areas on the map are from non-burnable fuel models in the LANDFIRE 2008 40-fuel-model layer, and may in some cases actually include agricultural lands capable of burning. The box inset in the lower left visually depicts the logic used to partition continuous WFP values into the five classes.

continuous or classified WFP products. Map graphics, spatial metadata, and other descriptive information are also available. The classified WFP raster data are also available as a map service from Environmental Systems Research Institute (ESRI) through their ArcGIS online website (ESRI 2013a), and can be viewed interactively on ESRI's Wildfire Public Information Map (ESRI 2013b).

Intended Uses and Applications of the WFP

The WFP map is a raster geospatial product that is intended to be used in analyses of wildfire risk or prioritization of fuels management needs at very large landscapes (millions of acres). On its own, WFP is not an explicit map of wildfire

Table 5—Area in the high and very high WFP classes, sorted in descending order by state, for the 23 states with over 1,000,000 acres in those two WFP classes.

		WFP Area (Millions of Acres) [a]		
Rank	**State**	**High**	**Very High**	**Sum**
1	California	14.18	21.19	35.37
2	Nevada	13.54	13.95	27.49
3	Idaho	17.23	7.64	24.87
4	Oregon	12.69	3.44	16.12
5	Utah	7.72	7.82	15.54
6	Arizona	10.85	3.10	13.96
7	Montana	6.49	3.97	10.46
8	Florida	7.52	1.73	9.25
9	Georgia	8.78	0.11	8.88
10	New Mexico	6.57	1.73	8.31
11	Washington	5.36	1.78	7.14
12	Colorado	5.30	1.58	6.88
13	Texas	4.96	0.24	5.20
14	Mississippi	5.05	0.08	5.13
15	South Carolina	4.91	0.05	4.96
16	North Carolina	4.06	0.38	4.45
17	Alabama	3.10	0.02	3.12
18	Wyoming	2.28	0.76	3.04
19	Minnesota	2.27	0.61	2.89
20	South Dakota	2.51	0.18	2.69
21	Oklahoma	2.24	0.11	2.35
22	Louisiana	1.95	0.01	1.96
23	Kansas	1.92	0.02	1.94

[a] Area is given in millions of acres, based on counts of 270 m pixels (each approximately 18 acres).

Table 6—Relative area in different WFP classes for US National Forest System lands, Department of Interior lands, and all lands in CONUS.

	National Forest System Lands			Department of Interior Lands [a]			All Lands	
WFP Class	**Area [b]**	**Percent**	**Percent of All Lands**	**Area [b]**	**Percent**	**Percent of All Lands**	**Area [b]**	**Percent**
Very Low	34.60	20%	2%	75.02	27%	4%	661.60	33%
Low	30.49	18%	2%	58.26	21%	3%	324.50	16%
Moderate	41.50	24%	2%	49.67	18%	2%	238.13	12%
High	35.26	21%	2%	38.84	14%	2%	154.85	8%
Very High	22.98	13%	1%	22.66	8%	1%	70.98	4%
High + Very High	58.24	34%	3%	61.50	22%	3%	225.82	12%
Non-burnable	4.86	3%	0%	27.42	10%	1%	442.19	22%
Water	0.66	0%	0%	2.55	1%	0%	102.99	5%
Total	170.36	100%	9%	274.42	100%	14%	1,923.22	100%

[a] Department of Interior Lands include: Bureau of Indian Affairs, Bureau of Land Management, Bureau of Reclamation, National Park Service, and US Fish and Wildlife Service.
[b] Area is given in millions of acres, based on counts of 270 m pixels (each approximately 18 acres).

threat or risk, but when paired with spatial data depicting appropriate HVRAs, it can spatially approximate relative wildfire risk to those specific resources and assets. However, this would only be appropriate for HVRAs where our weighting scheme for suppression difficulty is similar enough to the expected fire effects to serve as a proxy HVRA response function. In other words, WFP as a risk product is only suitable for HVRAs without any possible beneficial effects of fire, and where losses increase steeply with increasing fire intensity. Specifically, human communities that include built structures, infrastructure assets such as powerlines, and habitat areas for certain fire-sensitive species are examples of HVRAs that have this type of wildfire response function (Thompson and others 2013a). It is therefore critical to stress that using WFP as a stand-alone risk map across multiple HVRAs will tend to overestimate losses, and completely ignore beneficial fire.

The primary intended use of the WFP map, however, is for identifying priority areas for hazardous fuels treatments from a broad, national- to regional-scale perspective. The classified WFP product, in particular, allows for relatively quick identification of the land area within different geographic units (States, Forest Service regions, individual National Forests) with fuels that could present problems for wildfire suppression efforts or certain HVRAs under wildfire conditions. A manager or decision maker can quickly evaluate, therefore, the relative scope of fuels management work required in different geographic areas, and make informed decisions about allocation of funding and resources. Further, with the addition of spatial data depicting particular HVRAs or high-priority management concerns, these types of evaluations can be tailored to reflect agency fuels management priorities.

An example of Forest Service use of the WFP map to date is the identification of the total area nationally, and among Forest Service regions, at high priority for fuels treatment based on three goals from the National Cohesive Wildland Fire Management Strategy: 1) fire-adapted communities, 2) resilient landscapes, and 3) safe, effective fire response (WFLC 2014). From the WFP map alone, we can identify that roughly 58.24 million acres (34 percent of NFS lands) have either high or very high WFP, and could be considered as candidate areas for treatment. Of those, however, the highest priority acres are those where fuels treatments can achieve one or more of the Cohesive Strategy goals and are operationally feasible. Therefore, we incorporated several additional spatial datasets into our analysis:

- A spatial buffer zone around residentially developed areas, derived from a 2 km circular focal mean (moving window raster neighborhood analysis) of the national Residentially Developed Populated Areas (RDPA) dataset (Haas and others 2013). This zone reflects areas meeting both the fire-adapted communities and safe, effective fire response goals.
- High value watersheds for municipal surface drinking water supply, defined by 12-digit Hydrologic Unit Code (HUC) watersheds with a Forests to Faucets surface drinking water importance index of 70 or higher (Weidner and Todd 2011). These watersheds represent an important ecosystem service provided by Forest Service lands to neighboring human communities, and fuels treatments could help support both fire-adapted communities and resilient landscapes.
- Historic Fire Regime Groups from LANDFIRE 2008 (http://www.landfire.gov/fireregime.php), useful for identifying fire-adapted vegetation communities that experienced relatively frequent low- to mixed-severity fire historically (Fire Regime Groups I, II, and III). Treatments in these areas can help to advance the goal of resilient landscapes, as well as facilitating safe and effective response to future wildfires.
- Designated Wilderness and Roadless areas on NFS lands. As lands either congressionally (Wilderness) or administratively (Roadless) designated as places where mechanical treatment is restricted or prohibited, we removed them for consideration as high priority treatment areas (although prescribed fire could be used in either under the right circumstances).

Intersecting these spatial datasets with the classified WFP allowed us to develop categories reflecting different fuels treatment priority levels. Only considering areas within either the RDPA buffer zone or high-value watersheds, we identified the following categories:

1. High or Very High WFP, outside of Wilderness and Roadless, in Fire Regime Group I, II, or III. These are the highest priority areas (red on figures 13 and 14).
2. High or Very High WFP, outside of Wilderness and Roadless, in Fire Regime Group IV or V. These are acres where treatments might advance community or watershed protection objectives, but would be counter to the natural fire ecology of the vegetation, which would have been marked by infrequent, largely stand-replacement fire (pink on figures 13 and 14).
3. Very Low, Low, or Moderate WFP, outside of Wilderness and Roadless, in Fire Regime Group I, II, or III. These are acres that may not currently have hazardous fuels conditions, but based on the historic fire regime group they could move into high or very high WFP over time without treatments or disturbances to maintain the current condition. These are not the highest priority areas, but should be watched closely over time (yellow on figures 13 and 14).
4. All other areas that are either in Wilderness or Roadless, or have Very Low, Low, or Moderate WFP in Fire Regime Groups IV or V. At a National or regional scale, these would not be priority acres for treatment but local analysis might reach a different conclusion (green on figures 13 and 14).

Using this analysis, we identified 11.3 million acres of NFS lands in CONUS as being high priority fuels treatment areas (category 1 above). The distribution of these acres among Forest Service regions (figure 14) can help to inform managers of the relative fuels treatment workloads, and therefore guide allocation of budgets and resources. A

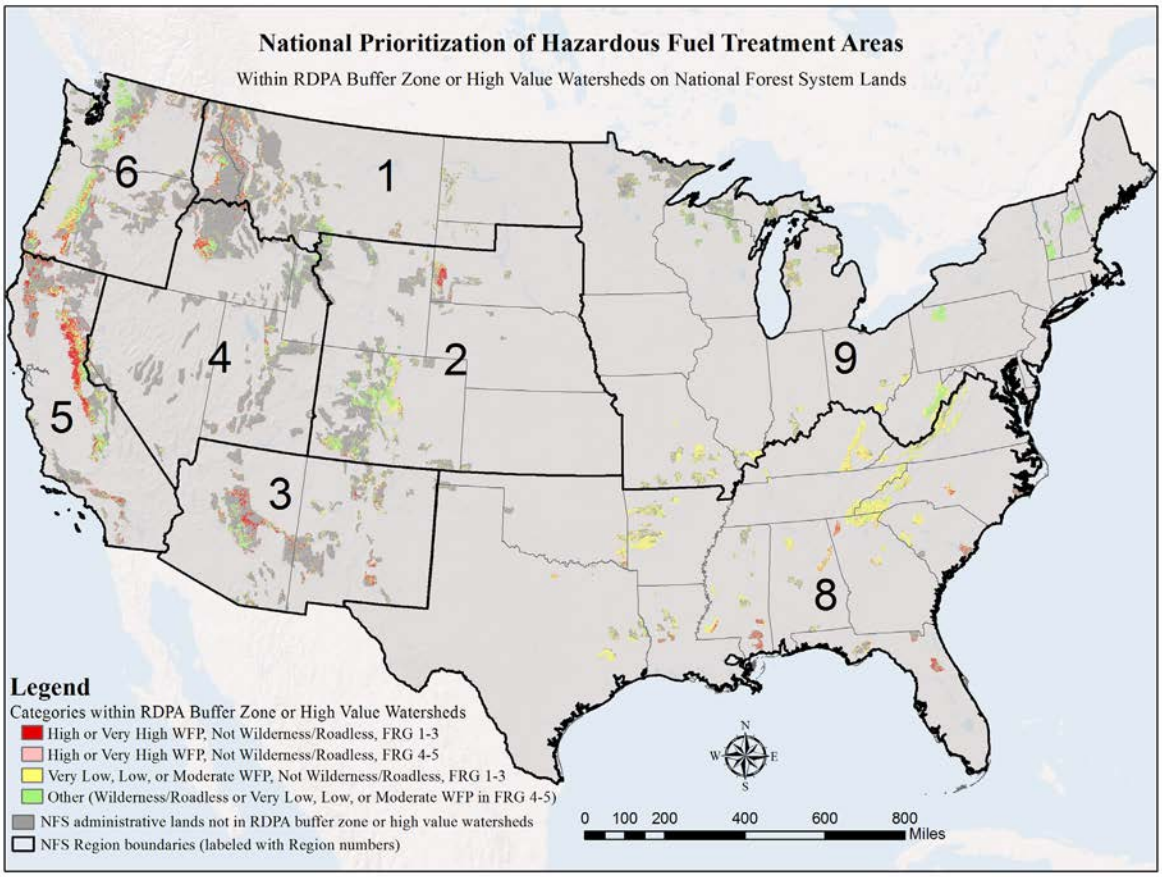

Figure 13—Map of the results from an analysis using the classified WFP along with other spatial data to conduct a national-scale prioritization of possible fuels treatment areas on National Forest System lands in the conterminous US. Based on this analysis, red areas on the map represent the highest priority and green represent the lowest priority.

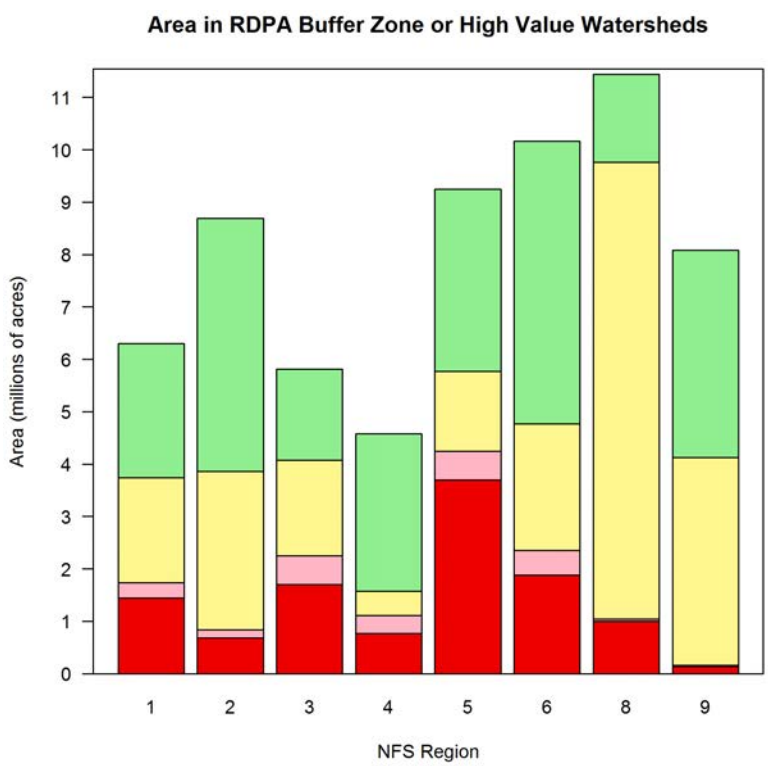

Figure 14—Land area within either residentially developed populated area (RDPA) buffer zones or high value watersheds on National Forest System lands, by Forest Service regions (x-axis). Colors in the bars correspond to map colors in figure 13, and represent land in different categories of fuels treatment priority. Red represents the highest priority areas and green represents the lowest priority for treatment.

risk-based analysis such as this, however, is just one of many factors that managers must consider in making these types of allocation decisions. Further, placement of actual treatments on the ground must be determined by local analyses, possibly using similar methods but factoring in critical local information that is too fine-scale for this type of national assessment (Calkin and others 2011).

Next Steps

The WFP map will be updated in the future as new LANDFIRE fuels and vegetation data, and subsequently national-scale wildfire simulation products, become available. The current 2012 WFP version was created with LANDFIRE 2008 data and wildfire simulation outputs generated from those data in 2012. The LANDFIRE 2010 data were released in 2013, and the latest FPA FSim runs using those data were completed in the spring of 2014. Therefore, a 2014 version of the WFP is imminent and will likely be released in the fall of 2014.

It is important to note that the WFP is not a forecast or wildfire outlook for any particular season, as it does not include any information on current or forecasted weather or fuel moisture conditions. The year associated with any version of the WFP indicates the year in which the map was produced, using the best available data at the time. In the case of the 2012 WFP, it reflects a 2008 landscape because that is the vintage of LANDFIRE data that were used in its creation. This is in contrast to the monthly and seasonal "significant wildland fire potential outlook" products produced by the Predictive Services program of the National Interagency Coordination Center and Geographic Area Coordination Centers, which are based on weather and fuel moisture forecasts.

In future versions of our map, beginning with the 2014 version, we plan to change the name from the Wildland Fire Potential (WFP) to the Wildfire Hazard Potential (WHP). By making this name change, we intend to avoid confusion between our product and the Predictive Services outlook products, and also to align better with standard wildland fire and risk assessment terminology (NWCG 2014, Scott and others 2013). The estimates of burn probability and intensity from FSim represent simulations of *wildfires*, as opposed to the more generic term *wildland fire*, and the integration of probability and intensity reflects the *hazard* posed by wildfires. Thus, we also feel that Wildfire Hazard Potential will be more descriptive of what the map really depicts.

Lastly, despite the temptation to compare subsequent versions of the WFP to indicate changes in fuels conditions across the landscape, we must caution against doing this. As mentioned previously, there have been significant changes in data quality, wildfire simulation methods, and WFP mapping methods between previous 2007 and 2010 WFP versions and the current 2012 version. While the mapping and modeling methodologies are stabilizing somewhat, we still anticipate some minor changes in future versions. Development of wildfire simulation outputs and subsequent products like the WFP map is an evolving science, and will continue to change as our knowledge advances.

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