Chapter 1: Fire and Fuels Reduction

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Introduction

Fire will continue to be a major management challenge in mixed-conifer forests in the Sierra Nevada. Fire is a fundamental ecosystem process in these forests that was largely eliminated in the 20th century. Fire reintroduction is a critical goal but is subject to constraints such as smoke production, risk of fire moving outside designated boundaries, the expanding wildland-urban interface, and lack of experience in burning large areas of forest. Recent fire and fuels research relevant to planning and implementing forest/fuels treatments revolve around three main topics: (1) potential limitations in the widely used Fire and Fuels Extension (FFE) module of the Forest Vegetation Simulator (FVS), (2) designing effective fuels treatment placement in landscapes under real world constraints, and (3) the size of high-severity burn patches in a landscape with an active mixed-severity fire regime. Although it currently may be difficult to model fire behavior in forests treated for the fine-scale structural and fuel heterogeneity suggested in U.S. Forest Service General Technical Report PSW-GTR-220, "An Ecosystem Management Strategy of Sierran Mixed-Conifer Forests" (hereafter GTR 220) (North et al. 2009a) collectively, the ideas presented may improve fuel treatment implementation and forecasting of wildfire effects on Sierran forests.

Modeling Considerations

Fire behavior predictions from FFE are critical in the evaluation of forest/fuel treatments (North et al. 2009a). These predictions rely heavily on the characterization of surface fuels. It is difficult, however, to both accurately measure all of the key characteristics affecting surface fuel pools (loads by size class, fuel bed depth, surface area to volume ratios by size class, heat content, etc.) and calibrate these values based on observed fire behavior. Therefore, fuels are often represented by established fuel models (Anderson 1982, Scott and Burgan 2005) that contain the collection of fuel properties needed to run the Rothermel surface fire spread model (Rothermel 1972), the basis for much of the fire behavior modeling done in the United States (Andrews et al. 2003; Finney 1998, 2006). Fuel models are determined internally in FFE based on forest structural characteristics, species composition, and, in some cases, site productivity (Rebain 2009, Reinhardt and Crookston 2003). Recent studies have identified some inadequacies with this internal fuel

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Summary of Findings

1. **Potential limitations in the widely-used Fire and Fuels Extension (FFE) module of the Forest Vegetation Simulator (FVS).** We discuss three limitations: (1) FFE's internal fuel model selection based on forest structure, which can lead to underestimation of fire behavior and crown fire potential; (2) problems with FVS's regeneration module, which produces higher live crown base heights over time that may incorrectly reduce torching potential; and (3) FFE's calculation of single stand-level inputs for fire behavior modeling, which may not capture variable fire effects in forests with fine-scale heterogeneity such as those proposed in GTR 220.
2. **Designing effective fuels treatment placement in landscapes under real world constraints.** Past research has provided a theoretical framework in the design of strategically placed landscape fuel treatments, but such designs are constrained by real landscapes. Two recent Sierran landscape fuel treatment projects were evaluated where treatment arrangement was based more on local knowledge than on intensive modeling. Results indicate that such treatments can be quite effective at reducing potential fire behavior.
3. **The size of high-severity burn patches in a landscape with an active mixed-severity fire regime.** Mixed-conifer fire regimes have commonly been characterized as frequent, low-moderate intensity before the onset of fire exclusion. Recent research has identified patches of high-severity fire as integral components of these regimes, but the vast majority of such patches were small. In upper mixed-conifer forests that have been subjected to over 30 years of burning by lightning fires, the median high-severity patch size was about 5 ac, while large patches, those >150 ac, made up <5 percent of the total patches by frequency. Some wildfires today are creating high-severity patches at much larger scales than are desirable to ecologists, managers, and the public.

model logic, particularly when incorporating the 40 Scott and Burgan (2005) fuel models (Collins et al. 2011a, Seli et al. 2008). Collins et al. (2011a) reported that the inclusion of FFE-selected fuel models when simulating fire across their study landscape resulted in a substantial underrepresentation of crown fire potential when modeling under 95th percentile wind and moisture conditions. This assessment of crown fire potential was based on a comparison between modeled crowning within their study area and observed crowning in two nearby wildfires, both of which occurred under wind and moisture conditions similar to those modeled. In a recent study, Cruz and Alexander (2010) pointed out inherent problems in our current fire modeling approaches, whether using FFE or other models such as NEXUS, that lead to the underprediction of crown fire potential. Regardless, model users should critically evaluate both the FFE-chosen fuel model(s) and the fire behavior output from FFE before finalizing modeling results. In instances where predicted fire behavior is noticeably different from observed fire behavior for similar stands/fuel complexes, overriding the FFE fuel model selection with a user-input fuel model is probably necessary.

Another potential problem with FFE model outputs of future fire behavior can result from limitations in the regeneration module in FVS. The FVS variants other than western Montana, central and northern Idaho, and coastal Alaska do not have the “full” regeneration establishment model (Dixon 2002). Consequently, most FVS variants do not model natural regeneration or ingrowth. In the absence of ingrowth, modeled development of undisturbed stands generally results in larger and taller trees with higher stand-level canopy base height. These conditions are modeled to produce self-pruning of the trees’ lower limbs. The net effect of this increase in canopy base height over time is reduced crown fire potential. This may or may not reflect reality. For example, Stephens and Moghaddas (2005) reported that 80 to 100-year-old mixed-conifer stands in the central Sierra Nevada, which regenerated naturally after early railroad logging and were subjected to minimal or no silvicultural treatments throughout their development (except full fire suppression), had high canopy base heights, and as a result, low potential for crown fire. Stands with similar structure and management history, however, may be rare in the Sierra Nevada. Many stands managed with either even- or uneven-age systems have higher potential for torching, mainly driven by lower canopy base heights (Stephens and Moghaddas 2005). The user-defined regeneration option in FVS is one way to manipulate the progression of canopy base height over time. The FVS user may need to experiment with different levels of regeneration in FVS to insure that model results are consistent with observational data from the actual stands that are modeled. A more comprehensive solution would be to collect and summarize long-term forest inventory data to support development of a full regeneration module for the western Sierra variant.

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Finally, the FFE module may have difficulty predicting fire behavior in forests with fine-scale structure and fuels variability that might be created using GTR 220 concepts. The FFE stand-level fire behavior predictions are based on a single value for each of the fuel/stand structure inputs: fuel model, canopy cover, canopy top height, canopy base height, and canopy bulk density. There can be substantial heterogeneity within many forest stands, whether driven by variability in underlying edaphic conditions or variability induced by management (Collins et al. 2011b, North et al. 2009a). Consequently, the fire behavior predictions may not completely reflect actual fire potential. For example, a stand composed of relatively dense tree clumps with sparser tree spacing between clumps may be predicted to support an active crown fire, when in an actual wildfire, only individual tree and small group torching may occur because of the canopy separations between the tree clumps. A relatively new output from FFE called P-Torch may help users capture some variability in predicted fire behavior (Rebain 2009, app. A). P-Torch is an index that estimates the probability of finding torching of small areas (33 by 33 ft) within a stand. Because it is a probability, which is based on fire behavior calculated for numerous random subplots as opposed to a threshold windspeed value (e.g., torching index), P-Torch may be better able to represent heterogeneous forest stands.

When more standard fire behavior outputs are required (e.g., flame length, fireline intensity), little can be done to correct for the modeling homogenization within FVS-FFE short of acquiring more detailed fuel/stand structure data and modeling at the substand level. A recent study using a detailed network of sensors found significant differences in microclimate, fuel moisture, and fire danger rating with fine-scale, topographically-induced weather variation (Holden and Jolly 2011). The increased acquisition of light detection and ranging (LiDAR) data may aid in capturing fine-scale variability in stand structure. However, these data are expensive, both for acquisition and for processing, and often cannot produce reliable information on surface fuels. Further, it is unclear how much, if any, improvement there is in fire behavior predictions when using higher spatial resolutions (e.g., 5- or 1-m pixels [3.3- or 16.4-ft]) vegetation/fuel inputs.

Landscape Fuel Treatment Design

The occurrence of increasingly large fires from warming climates and fuel accumulations (Miller et al. 2009, Westerling et al. 2006) warrants large planning scales for fuel and restoration treatment projects. In addition, the effort required for planning and analysis of alternatives tends to force larger project areas. However, infrastructure and funding limitations, combined with land management and operational constraints, limit the extent to which fuel and restoration treatments can be implemented across landscapes (Collins et al. 2010). As such, managers are forced to make choices about how to arrange discrete treatment units to collectively limit the spread of high-intensity wildfire across a landscape. Owing to the complexity of modeling fire and fuels treatments across landscapes (data acquisition, data processing, model execution, etc.), fuel treatment project design is often based on local knowledge of both the project area and past fire patterns.

Two recent studies in the northern Sierra Nevada suggest that such landscape fuel treatment projects (i.e., treatment arrangement was based more on local knowledge than on intensive modeling) can be quite effective at reducing potential fire behavior at the landscape scale (Collins et al. 2011a, Moghaddas et al. 2010). Reductions in potential fire behavior in two U.S. Forest Service projects were largely attributed to treatment unit arrangement relative to the dominant high-wind directions that typically occur throughout the fire season in each project area (fig. 1-1). In the Meadow Valley study area (Moghaddas et al. 2010), treatment units were arranged in a somewhat linear fashion with multiple "layers" across the landscape (fig. 1-1, left panel). These "layers" tended to be orthogonal to the "problem" wind direction in that area, which increases the potential for modeled fires to intersect treated areas. This orientation, combined with the multiple layers of treatments, resulted in reductions in modeled fire spread and intensity for "problem" wind-driven fires, which reduced the probability of high-intensity fire across much of the landscape. Aside from predictable reductions in intensity within treatment units, there were also pronounced effects on the downwind or lee side of treatments (fig. 1-1, left panel).

Landscape fuel treatment projects based more on local knowledge than on intensive modeling can be quite effective at reducing potential fire behavior at the landscape scale.

Treatment units in the Last Chance study area (Collins et al. 2011a) were much more clumped and centered about the long axis of the study area. In addition, the treatments were slightly shifted toward the upwind side of the study area (fig. 1-1, right panel). This treatment arrangement was quite different from that for the Meadow Valley area, but very effective at reducing the probability of high-intensity fire (fig. 1-1). Unlike Meadow Valley, Last Chance had multiple "problem" wind directions. By having relatively large, centralized treatment blocks that were placed more toward the upwind edge, Last Chance treatments may have been a good safeguard against modeled wind-driven fires spreading from multiple directions.

Accelerating the rate and extent of fuels reduction is needed because longer fire seasons and warmer temperatures associated with a changing climate (Westerling et al. 2006) may increase the potential for high-severity fire in Sierra Nevada mixed-conifer forests (Miller et al. 2009). Stand- and landscape-level reductions in hazardous fire occurrence can be achieved while incorporating heterogeneity into stand prescriptions (North et al. 2009a). Recent papers found most fuels

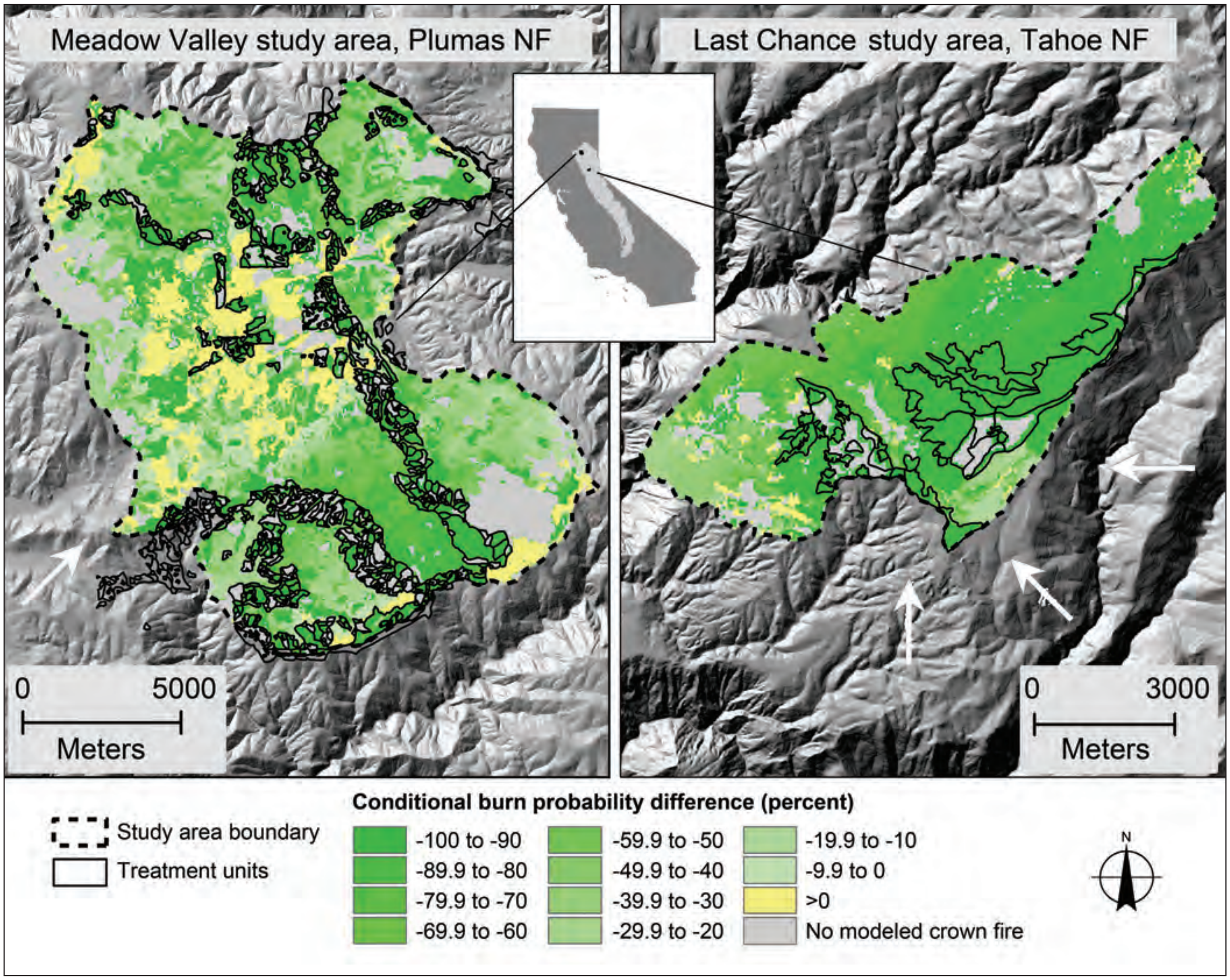

Figure 1-1—Posttreatment minus pretreatment difference in modeled conditional burn probabilities for two landscape fuel treatment projects in the northern Sierra Nevada. Conditional burn probabilities are based on 5,000 randomly placed ignitions simulated using RANDIG. Reported burn probabilities are for flame lengths that are consistent with crown fire initiation (see Collins et al. 2010a for explanation). The arrows represent the modeled “problem” wind direction(s) for each project. Note the different scales for the two projects; the approximate sizes of the study area are Meadow Valley 45,700 ac (18 500 ha); Last Chance 10,600 ac (4300 ha). NF = national forest.

treatments did not adversely affect many ecosystem services (Stephens et al. 2011) and had minimal impact on forest microclimate (Bigelow and North 2011) suggesting treatments may not compound warming trends. Forest resiliency at landscape scales (Collins et al. 2010) needs to be increased before changing fire regimes create conditions that managers and the public find unacceptable. The next one to three decades are a critical period in mixed-conifer forest management and conservation in the Sierra Nevada.

Mixed Fire Severity Across Landscapes

One of the concepts presented in GTR 220 is the ecological importance of fire in Sierran mixed-conifer forest (North et al. 2009a) as it applies to stand-level processes and structures, as well as landscapes. There are numerous studies documenting the historical occurrence of frequent, low-severity fires in mixed-conifer forests throughout the Sierra Nevada (Beaty and Taylor 2008; North et al. 2005, 2009b; Scholl and Taylor 2010; Skinner and Chang 1996; Stephens 2001; Stephens and Collins 2004; Taylor and Beaty 2005). Collectively, these studies suggest that historical forests had a low incidence of high-severity, or stand-replacing fire. However, issues of data availability and data collection associated with these historical reconstructions limit the inferences that can be made regarding more fine-grained stand-replacing fire effects, particularly when attempting to characterize fire over a landscape (Collins and Stephens 2010). These limitations lead to uncertainty in characterizing the "natural" role of stand-replacing fire in Sierra Nevada mixed-conifer forests. This information is important for determining acceptable levels of stand-replacing fire and designing forest/fire management strategies to achieve these levels. Areas that have allowed naturally ignited fires to operate on the landscape for multiple decades, such as the Illilouette Creek basin in Yosemite National Park and Sugarloaf Creek area in Sequoia and Kings Canyon National Parks, are possible points of reference for characterizing more natural forest/fire interactions in the Sierra Nevada. This is not to suggest that these long-term natural fire areas are a proxy for historical forest/fire interactions because despite having multiple decades of natural fire, these areas were affected by fire-exclusion policies for about 90 years prior to initiation of natural fire programs (Collins and Stephens 2007). Although there were noticeable impacts of fire exclusion, these areas represent fire regimes that are largely restored, which has particular relevance to current forest management given differences between historical and current/projected future climates (Collins and Stephens 2010). While both of these long-established natural fire areas are characterized as mixed-conifer forests, they are generally at higher elevations (6,500 to 8,000 ft) than much of the managed mixed-conifer forests throughout the Sierra Nevada. Dominant tree species in these areas are Jeffrey pine (*Pinus jeffreyi* Balf.), white fir (*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.), red fir (*A. magnifica* A. Murray), lodgepole pine (*P. contorta murrayana* (Balf.) Engelm.), and to a lesser extent, sugar pine (*P. lambertiana* Douglas).

Collins and Stephens (2010) studied stand-replacing patches within recent fires occurring in the upper elevation, mixed-conifer forests of the Illilouette basin. These fires were predominantly low to moderate severity, with about 15 percent of the fire areas classified as high severity (Collins and Stephens 2010). Patch sizes ranged from 1.3 to 230 ac (0.53 to 93 ha), with small patches (<10 ac)

Median stand-replacing patch size was 5.4 ac … the largest stand-replacing patches in the Illilouette basin (200 to 220 ac) were an order of magnitude or more below those that occurred in recent northern Sierra Nevada wildfires.

(4 ha) accounting for more than 60 percent of the total number of patches (fig. 1-2). Large patches (>150 ac) (60 ha) made up about 5 percent of the total number of patches, but accounted for nearly half the total stand-replacing patch area. Median stand-replacing patch size was 5.4 ac (2.2 ha). Perhaps most importantly, Collins and Stephens (2010) found that the largest stand-replacing patches in the Illilouette basin (200 to 220 ac) (81 to 89 ha) were an order of magnitude or more below those that occurred in recent northern Sierra Nevada wildfires (Antelope Complex and Moonlight Fire; 2,500 to 6,200 ac [1011 to 2509 ha]). The authors suggested three main implications from their study: (1) stand-replacing fire is a component of Sierra Nevada mixed-conifer forests (at least in upper elevation mixed conifer similar to the Illilouette area), but at relatively low proportions across the landscape (15 percent or less); (2) the distribution of stand-replacing patches consists of many small patches and few large patches; and (3) the stand-replacing patch sizes observed in recent Sierra Nevada fires (outside of natural fire areas) often greatly exceed the range of patch sizes reported for the Illilouette basin (Miller et al. 2009).

Malcolm North

Figure 1-2—Four-acre high-severity burn patch in the Illilouette basin that provides a high light environment for *Ceanothus* shrubs and pine regeneration.

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