Challenges and Approaches in Planning Fuel Treatments across Fire-Excluded Forested Landscapes

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ABSTRACT

Placing fuel reduction treatments across entire landscapes such that impacts associated with high-intensity fire are lessened is a difficult goal to achieve, largely because of the immense area needing treatment. As such, fire scientists and managers have conceptually developed and are refining methodologies for strategic placement of fuel treatments that more efficiently limit the spread and severity of fire across forested landscapes. Although these methodologies undoubtedly improve managers' ability to plan and evaluate various landscape fuel treatment scenarios, there is still a considerable gap between modeling landscape fuel treatments and actually implementing these treatments "on the ground." In this article we explore this gap in light of decisions managers make with regards to the type, intensity, placement/pattern, and size of fuel treatments. Additionally, we highlight several critical constraints acting on managers when implementing fuel treatments across landscapes and offer some suggestions for dealing with these constraints.

Keywords: fire exclusion, fire suppression, fire management, fire policy

Fuel reduction treatments are increasingly becoming the dominant forest management activity throughout western US forests, particularly in forests that historically burned under frequent, low- to moderate-severity fire regimes. The primary objectives of such activities are to modify wildland fire behavior to minimize negative impacts on forests (Agee and Skinner 2005), enhance suppression capabilities (Agee et al. 2000), improve firefighter safety (Moghaddas and Craggs 2007), and help restore ecological structure and function (McKelvey et al. 1996, Weatherspoon and Skinner 1996, North et al. 2007). Stand-scale studies have established the effectiveness of various fuel treatment alternatives at changing the behavior and reducing the impacts of both modeled fires (Fulé et al. 2001, Fiedler et al. 2004, Stephens and Moghaddas 2005, Schmidt et al. 2008, Stephens et al. 2009) and actual wildland fires (Martinson and Omi 2002, Skinner et al. 2005, Ritchie et al. 2007, Strom and Fulé 2007). These studies document tradeoffs among treatment types and provide guidance on designing prescriptions for forest stands. However, the extensive tracts of relatively homogenous, fire-excluded forests (Hessburg et al. 2005) throughout the western United States and the large wildfires that can occur in these forests (e.g., Rodeo-Chediski, Arizona 2002; Hayman, Colorado 2002; Biscuit, Oregon/California 2002; Murphy complex, Idaho 2007) show the pressing need to "scale up" insights gained at the stand level to landscapes. However, simply implementing fuel treatments across an entire landscape is infeasible. Lack of infrastructure (e.g., workforce, equipment, and roads), lack of funding, and management restrictions collectively limit the amount of area available for treatment.

In response, fire scientists and managers have conceptually developed and are refining methods for the strategic placement of fuel treatments across landscapes (Weatherspoon and Skinner 1996, Finney 2001, 2004, Stratton 2004, Finney et al. 2007).

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The basic idea is that an informed deployment of treatment areas, a deployment that covers only part of the landscape, can modify fire behavior for the entire landscape. However, this technique requires the synthesis of spatially explicit data to use process-based models of fire behavior and spread (FARSITE, Finney 1998; FlamMap, Finney 2006, Stratton 2006). Recent efforts have also integrated a stand-level vegetation model with the fire spread and behavior models (ArcFuels, Ager et al. 2006), providing a more accessible platform for testing various stand-level treatment alternatives (thinning, prescribed burning, or a combination of the two) across landscapes. Although these models and approaches undoubtedly improve managers' ability to plan and evaluate various landscape fuel treatment scenarios, there is still a considerable gap between modeling landscape fuel treatments and actually implementing these treatments "on the ground." In this article we explore this gap in light of decisions managers make and constraints acting on managers when implementing such activities. We also synthesize some of the current approaches, along with the requirements for using these approaches and offer some suggestions for dealing with the constraints.

Stand-Level Fuel Treatment Options

Types of fuel reduction treatments include fire (either prescribed or managed wildland fire), mechanical (e.g., thinning, mastication, and chipping), or a combination of the two. In field-based experiments Stephens and Moghaddas (2005), Schmidt et al. (2008), and Stephens et al. (2009) all found that prescribed fire alone effectively reduced surface fuels, thus reducing modeled rate of spread, fireline intensity, and flame length under a range of weather conditions. In addition, these studies also showed substantial reductions in ladder fuels in areas treated with prescribed fire. However, as fire-killed trees fall and contribute to surface fuel pools, the overall effectiveness in reducing potential fire behavior is lessened (Skinner 2005, Keifer et al. 2006). It is likely that in dense fire-excluded stands multiple burns will be needed to achieve more long-lived effects. Thinning effectiveness depends on the type of thinning performed and the subsequent treatment of activity fuels (Agee and Skinner 2005). In fire-excluded forests fuel reduction prescriptions often aim to both reduce ladder fuels (increase canopy base height) and increase crown spacing (reduce crown bulk density), in combination with removing activity and surface fuels (e.g., piling and burning or broadcast underburning; Agee and Skinner 2005). Whole-tree harvests [3] have also been shown to effectively reduce modeled fire behavior (Schmidt et al. 2008, Stephens et al. 2009). Data on tree mortality in thinned areas burned by actual wildfires, which show greater survivability in areas underburned after thinning, serve as real-world tests on the importance treating activity fuels after thinning (see Raymond and Peterson 2005, Ritchie et al. 2007).

The management decision with regard to the intensity of fuel treatments is driven by the following fire management goals: (1) minimize the threat to human life and property (including enhancing firefighter safety), (2) create/maintain more fire-resilient structure and ecosystem function, and (3) reduce the cost of fire suppression. Often, the intensity of a fuel treatment is manifested as a weather threshold under which the residual stand is expected to withstand wildfire-caused change. When the treatment involves prescribed burning, managers can choose to modify prescription parameters (seasonality, weather conditions during burning, fuel moisture conditions, and ignition pattern) to achieve desired effects. More aggressive prescriptions may include the following: late-season burning, lower relative humidity, lower fuel moisture, and strip headfire ignition pattern. Conversely, more conservative prescriptions involve early season burning, higher relative humidity, higher fuel moisture, and a backing or dot ignition pattern. Aggressive, late-season burns will consume a greater amount of surface and ladder fuel than a burn implemented under more conservative, early season conditions (Knapp et al. 2005), resulting in stands being more resistant to wildland fire under more severe fire weather conditions. However, more aggressive prescriptions increase the risk of a fire escaping and possibly causing unintended damage to other resources. The intensity of thinning treatments is often determined based on the residual stand structure desired after treatments. This can be expressed in terms of basal area, tree density, crown spacing, ladder fuels, and/or canopy cover. One important aspect of desired conditions is spatial heterogeneity in forest structure (Stephens and Fulé 2005).

Planning/Management Decisions

When designing landscape fuel treatments managers develop prescriptions to manipulate individual forest stands so that not only the treated stands withstand wildland fire under more extreme fire weather (e.g., 60–80% of overstory trees survive a fire under 90th percentile fire weather), but the fire-caused effects over the landscape are lessened as well. In developing stand-level prescriptions there are several decisions that must be made with respect to the type and intensity of the treatment (see side bar). Coordinating multiple stand-level treatments across a landscape involves making decisions on size of individual treatment units, the placement/pattern of the treatments, and the proportion of the landscape treated.

Size of Individual Treatments

The decision on how large to make individual treatments at the stand level also relates to the performance of the treated area when it encounters wildland fire. The larger the individual fuel treatment the greater the potential for tree survival, because of reduced edge effect mortality (Ritchie et al. 2007). Furthermore, larger individual treatments have a greater potential to reduce fire behavior and slow fire spread, which ultimately impacts adjacent untreated stands and should enhance suppression opportunities and increase firefighter safety. However, there are a number of constraints that limit the size of individual treatments that will be discussed in the following section. In addition, when planning multiple stand-level treatments across landscapes there are tradeoffs between the size of individual treatments and the dispersion of treatments across the landscape.

Treatment Placement

Using computer-based modeling, recent studies have explored various scenarios of treatment placement across forested landscapes (see Ager et al. 2007a, 2007b, Finney et al. 2007, Schmidt et al. 2008). Finney et al. (2007) show that treatment locations based on optimization algorithms (Finney 2004, 2007) more effectively reduce simulated fire growth across several landscapes compared with random location of fuel treatments. Schmidt et al. (2008) also report that regular arrangement of treatments outperformed random arrangement with respect to reducing fire spread and area burned. Planning fewer, larger individual treatments across the landscape appears to be a better strategy when human community protection is a primary concern (Schmidt et al. 2008). These larger treated stands can also be used as suppression or other fire management activity anchor points (Omi 1996, Agee et al. 2000, Moghaddas and Craggs 2007).

Treatment Proportions/Rates

Although only a few studies have explicitly modeled landscape fuel treatment effectiveness at different proportions of treated area, there are some common findings: (1) although noticeable reductions in modeled fire size, flame length, and spread rate across the landscape relative to untreated scenarios occurred with 10% of the landscape treated, the 20% treatment level appeared to have the most consistent reductions in modeled fire size and behavior across multiple landscapes and scenarios (Ager et al. 2007a, Finney et al. 2007, Schmidt et al. 2008); (2) increasing the proportion of area treated generally resulted in further reductions in fire size and behavior, however, the rate of reduction diminishes more rapidly beyond 20% of the landscape treated (Ager et al. 2007a, Finney et al. 2007); (3) random placement of treatments requires substantially greater proportions of the landscape treated compared with optimized or regular treatment placement (Finney et al. 2007, Schmidt et al. 2008), however, Finney et al. (2007) note that the relative improvement of optimized treatment placement breaks down when larger proportions of the landscape (∼40–50%) are excluded from treatment because of land-management constraints.

To our knowledge, Finney et al. (2007) is the only published study that compares effectiveness of different treatment rates over several decades. Their findings indicate that treatment rates beyond 2% of the landscape per year, based on optimized treatment placement, yielded little added benefit. This includes both the maintenance of previously treated units and the installation of new treatments throughout the 50-year simulation period. However, Finney et al. (2007) do note that "higher rates might be desirable in the first decade followed by later decreases."

Forest Dynamics

Finally, the dynamic nature of forest ecosystems imposes an important temporal consideration on landscape fuel planning. A suite of fuel treatments deployed strategically across the landscape will have a characteristic lifecycle. As the time since treatment lengthens, tree growth responses rebuild fuel load and fuel continuity (Agee and Skinner 2005, Collins et al. 2009). Thus, as stand-level treatments mature, the performance at the landscape level will decline (Vaillant 2008). Therefore, the design of landscape-level fuel treatments involves a tradeoff between maximizing the fraction of the landscape area treated at least once or treating a limited area repeatedly to maintain treatment effectiveness (Finney et al. 2007).

Constraints

Habitat Preservation

In choosing among the options for type, intensity, size, and placement/pattern of fuel treatments across a landscape, there are often conflicts between reducing potential fire behavior and protecting/conserving other resources. One of the conflicts often on the forefront is habitat for wildlife species of concern. In some cases these species prefer multistoried stands and/or closed canopies (e.g., northern spotted owl, *Strix occidentalis*; Pacific fisher, *Martes pennanti*; Solis and Gutiérrez 1990, Spencer et al. 2008). Although it has been argued that fire suppression and past harvesting practices have created much of the habitat that is being called "desirable" for species such as the spotted owl and fisher (see Spies et al. 2006), the species-specific approach toward managing forests continues to prevail (Stephens and Ruth 2005). This approach not only limits the intensity of fuel treatments, but the size and location of treatments as well. As a consequence, managers' ability to modify potential fire behavior, especially crown fire behavior, in forests with prolonged fire exclusion is restricted. Furthermore, regulations on forest management within and around nesting centers or natal dens (protected activity centers [PAC]) and riparian buffer zones affect the placement and/or pattern of fuel treatments (Figure 1). As such, the optimal placement of fuel treatments to maximize the reduction in fire spread and intensity across the landscape, such as the regular pattern described by Finney (2001), is limited in its applicability. Additionally, these protected areas are often highly productive and contain large amount of live and dead fuel; likely resulting in exacerbated fire behavior creating effects not only within these protected areas (Spies et al. 2006), but also in adjacent stands.

Human Communities

Wildland–urban interface (WUI) communities located within a given landscape or planning area can change the fuel treatment planning considerably. In most settings where WUI communities are adjacent to large tracts of publicly owned forests, placing fuel treatments around the WUI is a high priority. This not only affects the placement/pattern of fuel treatments across a landscape, but the harvest intensity and size of individual treatments. For example, because of exceptional potential losses from an escaped fire, prescribed fire treatments in the WUI would likely be smaller and involve more conservative prescriptions compared with more remote locations. Air quality concerns influence whether or when a prescribed burn is conducted. Smoke production from prescribed burns is monitored and regulated by regional air quality districts, and these districts need to approve burn plans and identify days for a prescribed burn to take place. This can further restrict an already limited "burn window," for which weather and fuel conditions are at a level that will allow for desired fire spread, intensity, and ecological effects while minimizing fire escapes.

Regulations and Appeals

A necessary step to successfully implementing any landscape-level fuel reduction project on federal public lands is for that project to satisfy the requirements of the National Environmental Policy Act of 1969 (NEPA) planning process. With respect to landscape fuel treatment planning the NEPA process requires comprehensive evaluation of the effects and impacts of various treatment scenarios, or alternatives, including a no treatment alternative. This process can be completed in a reasonable time frame for small projects but has been shown to take several years for landscape-level fuel treatment projects. Forest managers are often limited in time, and some cases expertise, when conducting these comprehensive evaluations. All projects contain a degree of risk or uncertainty that can not be reduced or explained with additional analysis. This is especially true when attempting to assess cumulative effects of multiple projects across a planning area. Those opposed to a particular fuel treatment project can appeal the plan on the basis of insufficient evaluation of either the alternatives or the associated impacts of the alternatives (Germain et al. 2001), which in many cases can never be fully known until the project is implemented. When appeals are denied, litigation can ensue, significantly delaying or even stopping fuel treatment projects entirely. The public can comment on the alternatives proposed. However, most projects generate few comments from the general public; the majority of comments received come from engaged interest groups who either support or oppose the project. The Healthy Forest Restoration Act (Healthy Forest Restoration Act [HFRA] 2003) was intended to streamline and expedite the planning and review process for fuel treatment projects (Stephens and Ruth 2005). However, it is unclear to what extent the intended effects of HFRA have actually been realized.

Despite the sound conceptual underpinning of strategic fuel treatments (Finney 2001), there is uncertainty regarding effective implementation. Specifically, it is unclear given current planning and operational constraints whether managers could successfully treat the amount of area recommended by fire modeling studies to appreciably modify fire behavior and effects over large landscapes (Finney 2001, Finney et al. 2007). The constraints on planning and operation include NEPA planning regulations, costs, lack of infrastructure (locally available contractors, smallwood processing facilities, and biomass-based power plants), and land designation restrictions. It is also unclear how landscape-level fuel treatments affect wildlife and water resources, both positively and negatively. Although there is general consensus that reducing fire severity is desired, there is no quantitative landscape data showing the positive and negative effects of these treatments on wildlife and water resources.

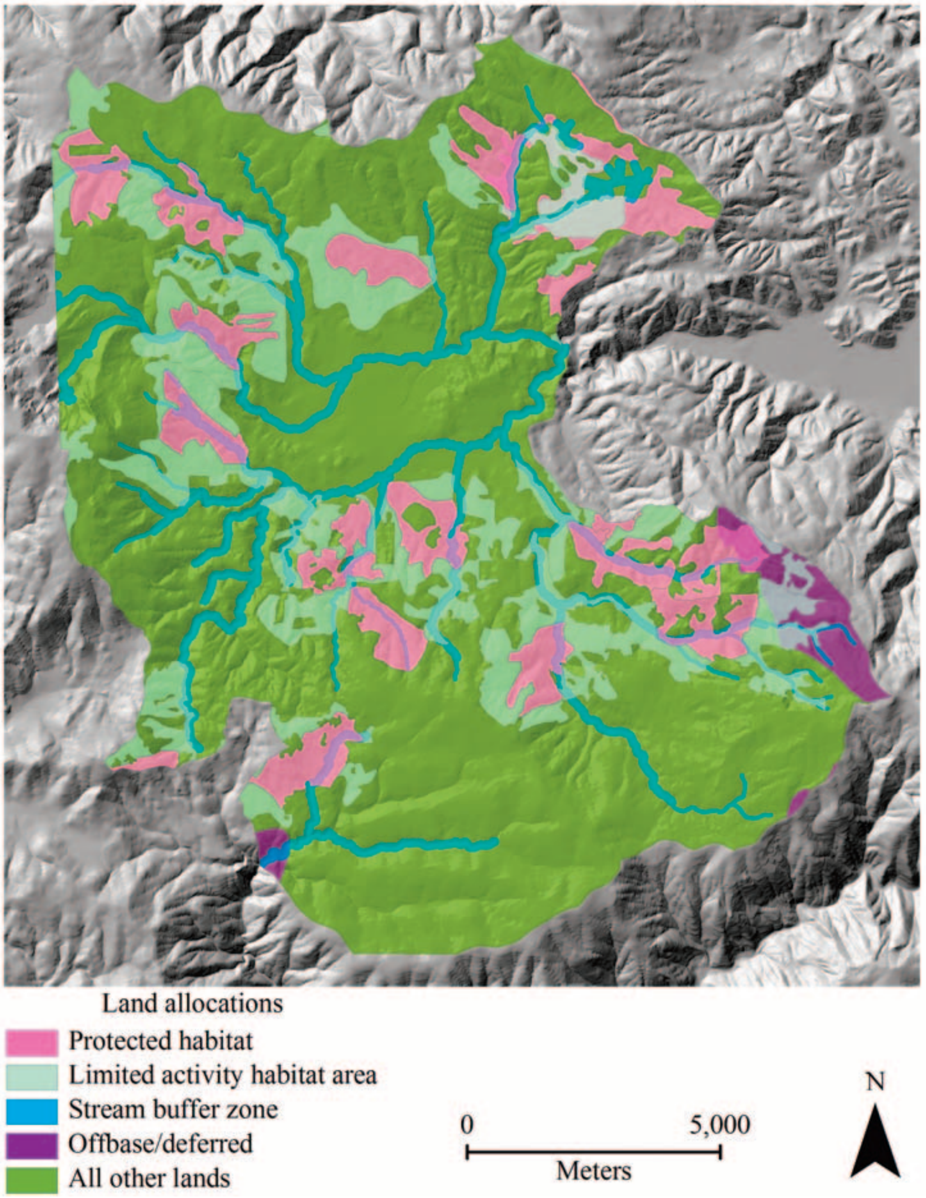

Figure 1. An example of area constraints on fuel treatment planning from the Meadow Valley area, Plumas National Forest, California. These are the actual land allocation layers provided by Plumas NF personnel. The protected habitat is for the California spotted owl (*Strix occidentalis occidentalis*).

Funding

Funding is still another limitation on landscape fuel treatment planning and implementation. The expected revenue or budget for a given project influences decisions on the type of fuel treatment that is conducted, as well as the size and placement of treatment units. For prescribed burning, costs can vary tremendously depending on factors such as treatment size, accessibility of treatment units, and complexity of terrain. In general, the costs per unit area decrease with increasing unit size because of the fixed costs of planning, staffing, and acquiring necessary resources for a prescribed burn (Hartsough et al. 2008). Given a limited budget and relatively high NEPA planning costs for small burn units (Hartsough et al. 2008), there may be tendencies to plan fewer, larger prescribed burns and implement them over a long period. This may result in fewer disparate large prescribed burns being performed than might otherwise be desired for optimal reduction of fire spread and behavior at a landscape level.

The costs/gains of thinnings depend not only on the size, accessibility, and terrain of treatment units, but also on the amount of merchantable timber harvested and its current market value, the amount and market value of biomass removed, and the treatment of activity fuels (Hartsough et al. 2008). In the fire-excluded forests throughout the western United States many of the trees to be removed in fuel reduction operations are below 15-in. dbh. In some cases the revenue from harvesting merchantable timber can pay for the service contracts needed to remove biomass and treat activity fuels. However, recently, funding such fuel reduction activities in Sierra Nevada forests with revenues generated from removing and selling merchantable timber has been called into question by the US Court of Appeals for the Ninth Circuit (Noonan 2008). This decision on whether fuel treatments should be subsidized or can be allowed to pay for themselves will impact the extent and rate of implementation of fuels projects.

Approaches

Given the decisions that must be made and the constraints on decision space when planning landscape fuel treatments, managers attempting to reduce fire spread and effects across a landscape are often charged with a difficult task. The following subsections provide both modeling and real-world approaches that can help in dealing with this complexity. The ideas presented are targeted toward management of large, contiguous tracts of forest where mitigation of uncharacteristic wildland fire effects is a dominant management priority. As such, these ideas may be more applicable to federal land management; however, some principles can be applied to state and private forests as well.

Modeling

ArcFuels (Ager et al. 2006) allows managers to explore the effects of numerous fuel treatment alternatives and scenarios. Because ArcFuels incorporates the Forest Vegetation Simulator (FVS; Dixon 2002) and the Fire and Fuels Extension (FFE; Reinhardt and Crookston 2003), it can simulate a wide array of prescribed burning, thinning, and combination treatments for any number of stands across a planning landscape. This tool allows users to tailor simulated treatment type, intensity, size, and placement/pattern relatively precisely to address the constraints imposed for a given landscape. Additionally, incorporating FVS allows for modeling the recovery/development of forests after treatments. [1]

ArcFuels can use LANDFIRE data (Landfire 2009) and forest inventory data (e.g., from Forest Inventory and Analysis plots), along with a map of individual forest stands, as inputs to then develop the specific files needed to run FARSITE and FlamMap. One of the main strengths of this tool is to compare modeled fire behavior and effects estimates for various alternatives of the "treated" landscape (i.e., after running user-assigned treatments to stands) to those for

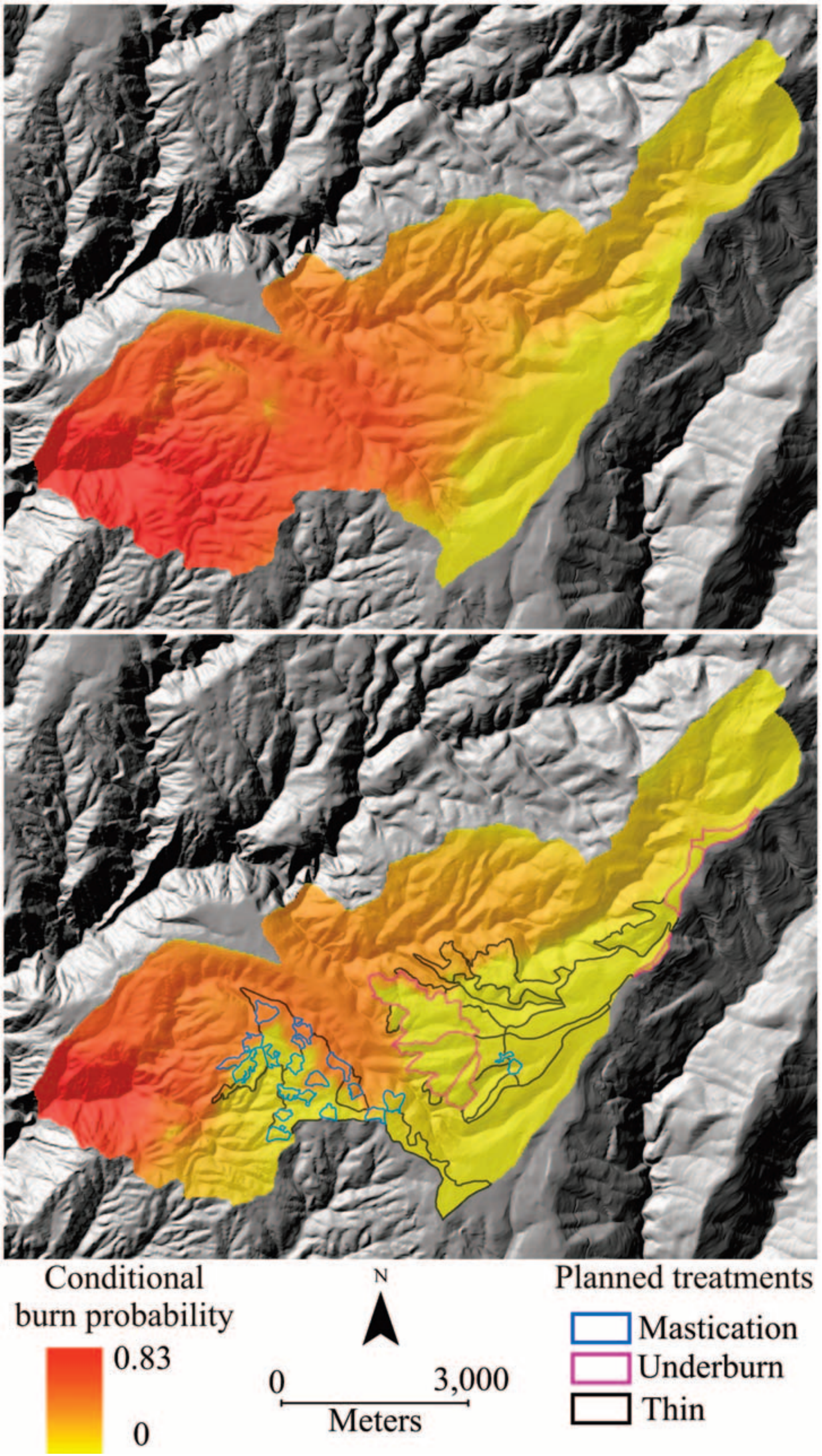

Figure 2. Conditional burn probability estimates for the Last Chance Project, Forest Hill Ranger District, Tahoe National Forest, California. These estimates were generated for pretreatment (upper) and modeled posttreatment (lower) landscapes using FlamMap and are based on 1,000 random ignitions. The treatments are planned as part of the Sierra Nevada Adaptive Management Project. This project is a collaborative effort between land managers, researchers, and interested groups and is designed to explicitly explore the effects of coordinated landscape fuel treatments.

the untreated landscape, as well as compare among treatment alternatives (Stratton 2006, Ager et al. 2007a, 2007b, Finney et al. 2007). This would allow for simulating scenarios such as placing fuel treatments adjacent to protected habitat (e.g., Ager et al. 2007a) or placing fuel treatments wholly within protected habitat, and then comparing such scenarios to one with no fuel treatments to examine potential fire behavior and effects across a given landscape. Similarly, one could evaluate the impact of including or not including various land ownerships in a landscape fuel treatment planning. This information on various fuel treatment alternatives is suited for the planning process that is mandated for management of federal and some state agencies (e.g., NEPA process). Establishing a substantial reduction in potential fire behavior and effects across a landscape for a chosen alternative can serve as defensible justification for performing fuel reduction treatments that may be needed when plans are questioned.

In addition to providing fire behavior estimates, the Minimum Travel Time feature within FlamMap can yield conditional burn probability estimates, as well as optimized locations for fuel treatments. Conditional burn probability estimates involve simulating a number of randomly ignited fires across a given landscape and can help identify areas most likely to burn if large fires occur (Finney 2006; Figure 2). The Treatment Optimization Model (TOM) within FlamMap identifies areas to treat, such that fire spread across a landscape (given a user-defined ignition and wind direction) is minimized (Finney 2004, 2006, 2007). Using the TOM requires a defined set of posttreatment fuel conditions for all areas where fuel treatments are possible, which can help managers address some of the fuel treatment placement constraints discussed earlier (e.g., not within PACs or WUI communities) and yield more realistic and useable outputs. Both of these tools within FlamMap can also help managers choose stands or areas and justify their selection for landscape fuel treatment planning (Figure 2).

The major limitation of the FlamMap and ArcFuels approaches for aiding managers in designing landscape fuel treatments, aside from the inherent model assumptions and limitations explained by Stratton (2006), is the expertise not only to gather and manipulate the necessary spatial data for these tools, but to execute the models and interpret the results. The Stewardship and Fireshed Assessment process currently underway in US Forest Service Region 5 is addressing this by bringing this expertise to individual forests, and even districts, in the form of interactive workshops that use local data to generate usable results (Bahro et al. 2007). This approach begins with the identification of a "problem" fire. The problem fire is one that has the greatest potential impact on human and natural resources based on historical weather patterns and terrain. Often, this fire is an actual wildland fire that occurred in the past under weather conditions that rendered suppression actions ineffective. Based on the problem fire the "fireshed" is delineated (25,000–100,000 ac) such that it includes areas with similar fire regimes, fire history, and wildland fire risk issues (Ager et al. 2006). The fireshed defines the scale at which fires and fuel treatments are considered and can be viewed as conceptually analogous to a watershed. Using the weather conditions, location, size, and effects of the problem fire, a treatment pattern is developed such that modeled fire behavior and anticipated effects are mitigated.

Assuming the expertise exists, this modeling framework used to meet immediate management needs can also be used to inform longer-term planning. For example, ArcFuels could be used to model forest growth in the future for both treated and untreated stands across a landscape. Subsequent analysis with FlamMap would provide insight into the lifecyle of landscape-level fuel treatments [2]. Although much work remains, these spatially and temporally explicit fire behavior models represent the most promising way to assess the longevity and effectiveness of fuel treatments. Such information is essential to the development of a comprehensive, long-term forest management strategy.

Real World

Outside of the modeling environment there are management decisions that can address some of the previously listed constraints. Planning to conduct prescribed fire treatments across multiple watersheds concurrently may be an approach for mitigating local air quality impacts. This would allow managers to incrementally implement treatments over a period of several years by rotating burning between various planning areas. This approach would effectively spread smoke impacts on affected communities out over time, and limit the potential for inundating a particular community with heavy smoke. As for funding constraints, particularly regarding fuel treatments in more remote and inaccessible areas, prescribed burning and managed wildland fire may be the most appropriate alternatives (Mills 2006, Collins et al. 2007, Collins and Stephens 2007). When prescribed burning in these areas, larger burns may be necessary to use landscape features as natural fuel breaks (rocky ridges, rivers, talus slopes, and more), thus keeping costs of fireline construction to a minimum.

Adaptive resource management is still another approach for managing landscapes where uncertainty exists in the response of a particular resource to management actions. It is a transparent process that involves testing, monitoring, and evaluating applied strategies and incorporating new knowledge into management approaches that are based on scientific findings and the needs of society. This process requires long-term commitments from scientists, stakeholders, and managers, which ultimately leads to more sound and informed decisionmaking. We recognize that outputs from adaptive management projects can be subject to changing economic and political priorities, and comprehensive results can take a decade or longer to generate. However, faced with the uncertainty of natural systems (Millar et al. 2007) and the current scale of fire hazard throughout the western United States, it is one of the few ways to move forward.

Conclusion

The impacts of extensive and severe fires in drier mid- to low-elevation forests are largely detrimental to the local ecosystem (Schoennagel et al. 2004, Keane et al. 2008). As the occurrence of larger, higher-severity fires is increasing in some areas of the western United States (Westerling et al. 2006, Miller et al. 2009) the need to mitigate these potential impacts is growing. We point out a number of challenges facing managers when attempting to plan and implement coordinated fuel treatments across forested landscapes. These challenges do not make the task of managing landscapes to prevent large-scale change from fire impossible; they simply mean we have to accept some uncertainty and resulting imperfection in implementing treatments, especially in initial efforts. The modeling approaches we summarize provide meaningful comparisons among treatment options/scenarios and can considerably improve the process of planning coordinated landscape fuel treatments. However, output from modeling is inherently subject to a certain number of assumptions and ideas put forth by the modeler and is no substitute for learning from actual treatments. Implementing landscape fuel treatments, even based on imperfect knowledge, and improving subsequent applications, will likely be a better alternative than the "no-action" alternative that continues to leave vast areas of forest susceptible to high-severity fire (Agee 2002).

Endnotes

[1] It is important that users of FVS/FFE evaluate and adjust, where necessary, fuel model selection based on knowledge local to the study site. If possible, users should calibrate fuel model selection with observed behavior and effects of an actual wildfire within or near the study area. Without such evaluation/adjustment results output from FVS/FFE can be suspect.

[2] A recent study (Vaillant 2008) showed the efficacy of such an approach.

[3] If whole trees are removed, the potential exists for some cost recovery by chipping small trees and transporting the chips to bioenergy plants. Depending on location of cogeneration infrastructure, as well as the status of a particular plants biomass supply, the cost of chipping and subsequent transport can exceed that of generated revenues. It is this availability of infrastructure that often determines the feasibility of biomass projects. However, when considering the alternative of treating activity fuels either by pile burning or by broadcast burning, which can be fairly costly (Hartsough et al. 2008), the potential losses associated with bioenergy use only need to be less than the costs of treating activity fuels to make such efforts worthwhile.

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