Effects of Fuels Management on Future Wildfires in the Lake Tahoe Basin

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Abstract

Fuel treatments have become an accepted means of mitigating the risk of high severity fires in the dry forests of the western US, and our current understanding of how fuel treatments affect wildfire relies on a variety of sources. Here we review what is known from research that is directly relevant to the Lake Tahoe Basin (LTB). Despite current scientific research across the western US and much general scientific study within the LTB, there is surprisingly little direct research on fuels management practices here. Fuel treatments can include various forms of thinning and/or prescribed burning, designed to reduce volume and continuity of fuels and subsequently decrease the risk of uncharacteristic fire effects. Of particular interest in the LTB are the effects of thinning treatments performed in conjunction with mastication – the chipping, crushing, or shredding of non-merchantable woody biomass (small trees and shrubs). Masticated fuel beds are difficult to study because current methods of fuel load estimation may not perform well, and adequate fuel models do not exist for them. Experimental and observational evidence suggests that masticated fuel beds may perform like activity fuels and increase severity of effects in post-treatment fires. Mastication followed by a surface fuel treatment such as prescribed fire may reduce tree mortality in future wildfire. Riparian areas are also of concern in the LTB because current management policy in the Sierra Nevada greatly restricts fuel management options and within these zones. Variation in fuel moisture, vegetation composition, and stream order may result in complex patterns of fire frequency, severity, and behavior within and between riparian areas. Prescribed fire has successfully been employed in riparian areas in the Sierra Nevada with minimal short-term effects on several biotic and abiotic characteristics, and water quality in LTB may also relatively unaffected by prescribed fire. Prescribed fire alone may not achieve management goals, depending on whether they are for fire hazard reduction or ecological restoration. Similar to riparian areas, options for fuel treatments on steep slopes are limited. Prescribed fire and/or jackpot burning, while difficult to implement in the LTB, may be the best option for these areas. Evaluation of treatment effectiveness depends on fire behavior and effects models, which have not been directly tested in the LTB. Model output could be improved

with better fuel models for treated stands (e.g. masticated fuel beds), or by improving inputs such as species bark thickness equations. Regardless of the models used, better fire weather information is needed for use in fire planning and management. Solutions to fire management problems in LTB are hampered by a lack of scientific research and a means for assessing tradeoffs between competing human and natural values.

Introduction

Although there is increasing uncertainty over how much of prehistoric forest landscapes burned in predictable low-intensity surface fires (e.g., Russell et al., 1998; Schoennagel et al., 2004; Hessburg et al., 2007), it is generally accepted that dry forest types of the western United States have been altered through over a century of novel conditions, particularly those that once experienced frequent, low-moderate intensity fire regimes (Agee and Skinner, 2005). Because these changes involve various land management practices – most notably fire suppression, but also logging, grazing, and urban development – simple time-since-fire metrics do not always predict areas that will burn at high severities (Franklin and Agee, 2003; Stephens and Ruth, 2005; Odion and Hansen, 2006). In contrast, patterns of extreme fire weather occurrence can act as consistent drivers of fire size and severity patterns, but we have limited knowledge of fire weather events in space and time. Regardless, many forests which experienced low-moderate or mixed severity fires prior to Euro-American settlement are now at greater risk of high severity, stand replacing crown fires that are often difficult to contain or suppress. This is a serious concern for the increasingly populated Lake Tahoe Basin (LTB).

Uncharacteristically severe fires are due in large part to changes in the structure of live and dead vegetation (fuels), such as increases in the volume and continuity of dead woody material on the forest floor (primarily surface fuels), decreases in forest canopy base height (increased ladder fuels), and increased density of forest canopies. These alterations can result in increased surface fire intensity (heat output), increased ability of fire to reach forest canopies, and increased capacity for fire to spread through the canopy. The net outcome is more severe fire effects on forest resources and greater difficulty for firefighters in protecting life, property, and values at risk, particularly where human development on fire-prone landscapes has created a complex wildland-urban interface (WUI) problem. Alteration of vegetation structure and continuity of fuels has become an accepted means of mitigating the risk of high severity fires (Grahm et al., 2004). Fuel treatments can include various forms of thinning and/or prescribed burning designed to reduce volume and continuity of fuels, and subsequently reduce the risk of uncharacteristic fire effects. Retaining the largest trees in forest stands also increases the resistance to high severity wildfire (Agee and Skinner, 2005; Stephens and Moghaddas, 2005a).

Policy and Management Context

The general goals of fuels treatments – to reduce fire hazard, restore ecosystem health, or both – are generally agreed upon. However, specific application of fuel treatments by skilled fire and fuels managers requires careful consideration of many issues, such as where and when to apply limited resources to vast areas of forests that may be in need of fuel treatment. What types of fuel treatments to apply can be a difficult problem, given that different treatments in different locations have varying effects, not only on potential fire behavior but on other forest resources as well. Fuel treatment decisions have potential ramifications in terms of air quality, water quality, wildlife habitat, soil resources, vegetation communities, and many other ecosystem elements (Collins et al., 2007; Kobziar et al., 2007; Amacher et al., 2008; Moghaddas and Stephens, 2008), issues covered by other papers in this volume. Additionally, fuel treatments should be considered in the context of larger land management goals and policies.

The Lake Tahoe area stands out not only for its natural beauty but also as a striking example of the complexity of managing fire and fuels in the altered forests of the western United States. Since its sighting in 1844 and subsequent displacement of the native Washoe, over 150 years of Euro-American settlement and varying land uses (e.g., recreation, timber production, commercial fishing, grazing and urban development) have altered the terrestrial ecosystems of the LTB dramatically from pre-settlement conditions (Elliott-Fisk et al., 1996). Much of the forested land of the LTB today is relatively young, densely stocked, and generally homogenous, owing to intensive logging efforts in support of Comstock Era mining. Urban development within many areas of the LTB has created extensive WUI areas in which the necessities of fire-safety and structure protection become intermixed with goals of resource protection and overall forest health. Recreation and tourism, the primary industry in the LTB today, depends greatly on the quality and health of the Lake Tahoe ecosystems (Elliott-Fisk et al., 1996). Changes in ecosystem elements such as water quality, air quality, wildlife habitat, soil resources, and plant communities affect both the residents living in the WUI and people visiting for the beauty and vast recreational opportunities. Both groups depend in direct and indirect ways on forests that are not only fire-safe but also ecologically resilient.

Fire planning and fuel treatment efforts around the basin have begun to address this situation, but land management and planning in the LTB is complex. The Tahoe Regional Planning Agency (TRPA) regulates land use in the basin involving federal agencies, two states, local governments, private landowners and non-profit and collaborative groups with stakes or responsibilities in the LTB. National forests collectively cover 78% of the land in the basin and are managed as the Lake Tahoe Basin Management Unit (LTBMU). Fire and fuel management by these groups occurs in the context of many environmental and social issues within the basin. Effects of land use decisions on lake clarity, water quality, air quality, soil erosion, sensitive species, the recreation industry, and economic development are all critical considerations. Past efforts, such as the Sierra Nevada Ecosystem Project (Elliott-Fisk et al., 1996) and the Lake Tahoe Watershed Assessment (Murphy and Knopp, 2000), and current ones, such as the

Comprehensive Science Plan for the Lake Tahoe Basin, have attempted to synthesize knowledge and identify key questions relating to the health and future of the LTB environment.

Ecological and Scientific Context

Wildland fire operates on many different spatial and temporal scales. In an annual and stand-level context, the process of combustion of live and dead vegetation serves to reduce above-ground biomass that has built up over some period of time. Forests can increase or decrease in fire hazard (Johnson and Gutsell, 1994) as fuels build up on the ground and in the vegetation canopy. Depending on how often a region is exposed to extreme fire weather conditions, fire hazard may be less constrained by time since the last fire and fuel accumulation (Moritz, 2003). A relevant example in the LTB may be the region near South Lake Tahoe, which experiences relatively severe fire weather episodes and has a long history of severe fire events (Russell et al., 1998; Murphy et al., 2007).

First order fire effects are those that occur as a direct or immediate result of the combustion process. Examples include plant mortality, either by combustion or by exposure to lethal temperatures for sufficient durations, atmospheric emissions, and reduction of fuel biomass. On landscape and multi-annual scales, fire serves in many systems as a natural form of ecological disturbance. The frequency, seasonality, size, intensity, severity, spatial complexity, and type of fires that typify a particular landscape define its fire regime (Gill, 1975). Alteration of fire regimes outside their natural range of variability, such as those changes resulting from historical land management practices or from current fuel treatments, can have consequences for fire behavior, and subsequent first order or secondary effects. Defining desired future conditions or trends for a landscape and methods for achieving those conditions should consider these consequences.

Our current understanding of how fuel treatments may alter fire behavior and effects in western forests relies on several sources: our scientific understanding of fire ecology in various forest types, anecdotal and direct observational evidence of wildfire in treated and untreated areas, pre- and post- wildfire vegetation monitoring studies, fuel treatment experiments, and our ability to predict fire behavior and effects through models. Current models in use include models for surface fire behavior (Rothermel, 1972), crown fire initiation and spread (Van Wagner, 1977), fuel beds (Anderson, 1982; Scott and Burgan 2005), fire effects (Ryan and Reinhardt, 1988), and those that integrate multiple aspects of fire behavior and effects (Finney, 1998; Carlton, 2004). Most experimental or monitoring studies necessarily use fire models, as studying wildfire under the conditions that fuel treatments are intended to address is often impossible. In a few instances, areas that had been treated in the recent past have burned in wildfires, providing opportunity for study (Stephens et al., 2008a).

Several goals guide the implementation of fuel treatments in forested ecosystems, including reducing fire size and spread rate, keeping fire out of the canopy, and decreasing fire intensity. Protecting lives, structures, and values at risk, improving effectiveness of firefighting efforts, and creating safety zones and avenues for firefighter egress are also key considerations. In terms of resiliency and forest health, fuels treatments can be designed so that during a hypothetical ―problem fire” (e.g. near-worst case scenario) some proportion of the forest trees will survive. Locating treatments on the landscape to achieve the above goals is a topic of current research and debate. Defensible fuel profile zones (DFPZs) (Agee et al., 2000) and strategically placed landscape area treatments (SPLATs) (Finney, 2001) are two current models for this.

While a substantial general literature exists for many ecosystem elements in the LTB, our understanding of pre-settlement vegetation structure and condition, pre-historical fire regimes, and other topics that can inform fire and fuels managers is still developing. Recent work (Taylor, 2004; Taylor and Beaty; 2005; Beaty and Taylor, 2007) has helped to forward our understanding in LTB of contemporary old-growth and pre-settlement stand structure, fire regimes, and exogenous factors contributing to fires patterns on the landscape (e.g. climate). Taylor (2004) established reference conditions for Jeffrey pine-white fir (Pinus jeffreyi Grev. & Balf. – Abies concolor (Gordon & Glend.) Lindley), red fir-western white pine (Abies magnifica Andr. Murray – Pinus monticola Douglas), and lodgepole pine (Pinus contorta ssp. murrayana (Grev. & Balf.) Critchf.) forests on the eastern shore of Lake Tahoe. Comparison to current conditions showed that contemporary Jeffrey pine-white fir forests are denser and more homogenous than presettlement, while current red fir-western white pine forests are also denser but have more lodgepole pine than their presettlement counterparts. Taylor (2004) and Taylor and Beaty (2005) also established fire regime characteristics for these forests, showing years of widespread presettlement fire to be closely associated with drought. Beaty and Taylor (2007) estimated fire regime parameters for old-growth mixed conifer forests on the West Shore, showing fire return intervals of 9-17 years for 0.5 ha (~ 1 acre) plots. Previous work in remnant old-growth forests in the LTB (Barbour et al., 2002), in addition to relatively intact Jeffrey pine-mixed conifer forests in northern Baja California (Stephens and Gill 2005, Stephens et al. 2008b), can assist in our understanding of forest dynamics in the LTB. Studies within the Sierra Nevada and in similar coniferous forest types in the western United States may also help to further our understanding of forest dynamics, potential fire behavior, and ecological effects.

Key Questions

Despite current scientific research efforts regarding fire and fuels management in the western United States and much general scientific study within the LTB, there is a surprising dearth of direct research on fuels management practices in the LTB. This paper is part of a larger effort by the U.S. Forest Service Pacific Southwest Research Station and the Tahoe Science Consortium to review available scientific literature relevant to fuel treatments and their effects on ecosystems in the Lake Tahoe Basin, as an aid to land and fire managers in the LTBMU. The specific goal of this paper is to synthesize scientific information that may facilitate an understanding of the effects of varying potential fuel treatment methods on future wildfire behavior and first order effects in the LTB. The LTBMU staff has identified specific questions of concern to be addressed in this review:

1. What fire behavior and effects can be expected during a wildfire in chipped and masticated treatment units where biomass is left on site?
2. What is known about wildfire in unmanaged stream environment zones (SEZs)?
3. What evidence is there for treatment effectiveness on steep (i.e. >30%) slopes, which constitutes much of the LTB?
4. How well do current fire effects models work in the LTB?

Fire and Masticated Fuel Beds

Thinning treatments to reduce ladder or crown fuel volume or continuity are increasingly being performed in conjunction with mastication – the chipping, crushing, or shredding of non-merchantable woody biomass (small trees and shrubs) – with the goals of reducing crown fire activity (by removing ladder fuels), surface fire intensity (by reducing fuel bed depth), and subsequent tree mortality. Masticated materials from these operations are often left on site, under the premise that this shorter, more compact fuel bed will meet these goals. Total fuel load is not reduced immediately unless biomass is removed from the site, or mastication is followed by a surface fuel treatment such as prescribed fire. Mastication does change fuel bed characteristics such as depth, bulk density, moisture absorption and packing ratio, as well as fuel particle characteristics such as shape and surface area to volume ratio (Kreye and Varner, 2007; Kane, 2007), and thus presumably changes fire behavior. While flaming front surface fire intensity may be reduced or increased, the more dense fuel bed may result in longer flaming or smoldering combustion, and subsequently longer heat pulses to the forest floor and vegetation, possibly causing higher levels of mortality. These potential changes in future fire behavior and effects have not been well quantified. They are difficult to study because current forms of fuel load estimation (e.g. Brown, 1974) may not perform well for masticated fuel beds, where materials are of different shape and sizes than natural fuels (Hood and Wu, 2006; Kane, 2007). Additionally, adequate generic fuel models for use with the Rothermel (1972) fire spread model (e.g. Anderson, 1982; Scott and Burgan, 2005) do not currently exist for chipped or masticated fuel beds (Kane, 2007).

To date no published work specifically on fire behavior or fire effects in masticated fuel beds exists for the Lake Tahoe region. Performance of masticated fuel beds has been addressed experimentally in several studies by either: 1) measuring pre- and post-treatment fuel beds and estimating potential fire behavior and effects through standard or modified-standard fuel models, or 2) directly measuring fire behavior and effects during prescribed fire. In a replicated experimental study examining fire and fire surrogate treatment effects in the Blodgett Experimental Forest (north-central Sierra Nevada, approximately 35k west of the LTB), Stephens and Moghaddas (2005b) found that fuel beds resulting from prescribed fire treatments and mechanical treatments (thinning and mastication) followed by prescribed fire, performed the best in terms of predicted fire behavior and tree mortality. Mechanical treatments alone also reduced predicted fire behavior and mortality as compared to controls, but still resulted in high mortality under severe fire weather conditions. They conclude that mastication is effective at reducing ladder fuels, but also increases surface fuel depth and continuity, which can result in more severe fire effects. In a study of mastication and spring prescribed fire in mixed shrub woodlands in the Whiskeytown National Recreation Area of northern California (Bradley et al., 2006), masticated fuel beds subjected to prescribed fire resulted in greater heat outputs and mortality of overstory and pole-sized oaks and conifers, when compared to non-masticated treatment units. Busse et al. (2005) found that lethal soil temperatures (>60 deg. C or 140 deg. F) could be reached with burning of masticated shrub fuels, particularly in dry soils with masticated fuel beds > 7.5cm (3 in.) in depth. Prescribed fire in masticated fuel beds in sites in the northern Sierra Nevada and southern Cascades (Knapp et al., 2006) resulted in higher than expected overstory crown scorch, and subsequent tree mortality.

The ultimate test of fuel treatment effectiveness is performance under real wildfire conditions. Examples of this are obviously rare, and analysis of treatment performance is usually either observational/anecdotal (fire behavior) or post hoc (fire effects). In a study of four wildfires in the Sierra Nevada, Hansen and Odion (2006) found that fire-induced mortality was greater in 5 of 6 thinned sites when compared to unthinned sites. The remaining site had been masticated months prior to the wildfire, and showed lower mortality when compared to unthinned site. Empirical evidence for fuel treatment effects and effectiveness during several large fires (Hayfork, Tyee, Megram, Hayman, and Cone) was summarized by Agee and Skinner

(2005). They conclude that important considerations include treatment of residual treatment/activity fuels, scale of treatment units, and age of treatment units. The Biscuit fire afforded a rare opportunity for study, when it burned through previously treated forest stands. Though residual surface fuels were not masticated, thinning-only treatments resulted in higher surface fuel loads, and subsequently higher surface fire intensity and greater mortality from the Biscuit fire than those treated with a thinning followed by prescribed fire (Raymond and Peterson, 2005). Similar results were found after the Cone Fire burned through pre-fire treatments at Blacks Mountain Experimental Forest in Northern California. Ritchie et al. (2007) found that probability of tree survival after the Cone Fire was greatest for areas treated with thinning and prescribed fire, whereas in thin-only units it was substantially less, but still much better than the untreated forest. Though the latter two examples don‘t deal directly with mastication, they serve to underscore the point that increases in surface fuels from treatments can have adverse effects on fire behavior and tree mortality.

The Angora Fire, one of the highest profile fires in the west in 2007, is the closest and most recent example of fuel treatment effectiveness in the LTB. There were 194 ha (480 acres) of treated US Forest Service land burned in the fire, of which only 30 ha (75 acres) burned as crown fire (Murphy et al., 2007). While fuel treatments did not include mastication, they did consist of pre-commercial and commercial thinning, followed by hand thinning, piling and burning (Murphy et al., 2007). Several efforts are underway to evaluate the efficacy of the fuel treatments, as well as effects of the fire on other forest ecosystem elements (Safford pers. comm.).

Highlights

- Current forms of fuel load estimation may not perform well in masticated fuel beds since masticated materials are of different shapes and sizes than natural fuels.
- Adequate generic fuel models for use with the Rothermel fire spread model do not currently exist for chipped or masticated fuel beds.
- To date no published work specifically on fire behavior or fire effects in masticated fuel beds exists for the Lake Tahoe region.
- Important considerations for masticated fuel beds may include treatment of residual fuels, scale of treatment units, and age of treatment units.

Fire and riparian environments

Historical logging did not tend to discriminate between upland and riparian forests, yet current management policy of riparian environments in the Sierra Nevada – often called stream environment zones (SEZs) – greatly restricts fuel management options and activity within these zones. This raises questions about the degree to which fire suppression has altered natural fire frequencies and severities in SEZs. Observations of wildfires and additional anecdotal evidence suggest that “unmanaged” or unaltered SEZs may, under certain conditions, exhibit rapid rates of fire spread. Deciding whether or not to leave SEZs in their current state, however, will require a possible tradeoff in competing risks and values (e.g., water quality, habitat, and fire hazard), and acceptance of compromise is likely in LTB. To address this issue, it is also necessary to have some understanding of the prehistoric conditions within SEZs, an assessment of the fire behavior and expected effects if left unaltered, and a clear definition of desired future outcomes and related inherent tradeoffs.

Although there are several recent papers reviewing different aspects of wildfire in riparian areas (e.g., Bisson et al., 2003; Dwire and Kauffman, 2003; Reeves et al., 2006; Pettit and Naiman, 2007), there is general agreement about a lack of knowledge concerning fire in these environments. There is no published work on wildfires and SEZs in LTB. It is widely held that fires burned prehistorically in many SEZs, but less often than in upland areas, due to higher moisture levels in live and dead fuels closer to watercourses. Wind speeds may be lower than in surrounding uplands, which can lower fire intensities in riparian areas, although channeling of winds in steeper riparian areas could occur. Some have noted that fire frequencies in drier environments may be similar between riparian and upland areas (e.g., Dwire and Kauffman, 2003); others report similar average fire intervals but higher variation in riparian areas (Skinner 2003). In general, variation in fuel moisture, vegetation composition, and stream order may result in complex patterns of fire frequency, severity, and behavior within and between SEZs. Depending on conditions during a given fire, some riparian areas are therefore likely to act as barriers to spread, while others might burn more readily (Taylor and Skinner, 2003; Pettit and Naiman, 2007).

Given the lack of reference conditions for these areas and the heterogeneity of fire behaviors to be expected in SEZs, it is still unclear what constitutes ―uncharacteristically severe" fire in riparian areas. Although the recent Angora Fire in LTB was catastrophic in human terms, was the high severity riparian burning that occurred during extreme weather conditions outside the natural range of variability? Due to higher biomass productivity in SEZs, some sections will naturally capable of carrying higher severity fires during periods of drought and dieback or during episodes of extreme fire weather (Agee, 1998). Accommodation of a range of natural disturbance severities, both due to fire and other physical processes, is actually necessary to maintain riparian habitats and biodiversity (Bisson et al., 2003). Some degree of high severity burning is therefore to be expected in SEZs, similar to mixed severity fire regimes of higher elevation coniferous forests.

In terms of fire regime restoration alone, SEZs have been classified as relatively low priorities for fuel treatments. Where concerns over fire hazard are considered of paramount importance, riparian areas are still viewed as sensitive to mechanical fuel reduction techniques, and prescribed fire is seen as the most appropriate tool (Weatherspoon and Skinner, 1996; Brown et al., 2004). Prescribed fire has successfully been employed in riparian areas with minimal short-term effects on several biotic and abiotic characteristics (e.g., Beche et al., 2005), and water quality in LTB may also relatively unaffected by prescribed fire (e.g., Stephens et al., 2004). There is some evidence for shifts in species composition in riparian areas due to fire suppression, such as conifer encroachment (Kobziar and McBride, 2006). The lack of fire and the relatively high site productivity in and near riparian areas has resulted in the production of many large trees in the past 100 years. In one study, high intensity prescribed fire was applied to reduce fuel loads and increase the light for deciduous plants near streams, but it was not successful in reducing tree density in mixed conifer forests in the Sierra Nevada (Beche et al., 2005). Reduction of tree encroachment in riparian areas may therefore require the use of mechanical methods, since trees have become large enough to be very difficult to kill by prescribed fire. If mechanical methods are deemed necessary for habitat restoration in riparian zones, approaches would need to be designed to limit soil disturbance, compaction, and erosion.

Due to higher moisture levels, riparian zones in Sierra Nevada forests normally should not act as ―fuses” to carry fire across portions of the landscape where efforts to limit fire spread would otherwise be successful (Weatherspoon and Skinner, 1996). Regardless, decisions regarding fire hazard in riparian areas will ultimately be made in the face of uncertainty and competing values (Bisson et al., 2003), so some tradeoffs between the needs of human and ecological systems may be inevitable.

Highlights

- Although there are several recent papers reviewing different aspects of wildfire in riparian areas, there is general agreement about a lack of knowledge concerning fire in these environments. There is no published work on wildfires and SEZs in LTB.
- Variation in fuel moisture, vegetation composition, and stream order may result in complex patterns of fire frequency, severity, and behavior within and between SEZs. It is still unclear what constitutes ―uncharacteristically severe" fire in riparian areas.
- Riparian areas are still viewed as sensitive to mechanical fuel reduction techniques, and prescribed fire is generally seen as the most appropriate tool, although in some areas encroaching conifers have become large enough to be very difficult to kill by prescribed fire alone.

Fire and steep slopes

A large portion of LTB is characterized by relatively steep slopes (i.e. >30%). Fire behavior and spread up steeper slopes is analogous to that observed under higher wind speeds, as flames are not perpendicular to the ground surface and more rapidly preheat the fuels ahead of the flaming front. While many of these areas are experiencing similar changes to forests of more moderate slopes (i.e. higher tree densities, fuel loading and continuity), fuel treatment options in these areas are often limited. Erosion potential on steep slopes is much higher, so vegetation modification there can be detrimental to soil stability and water quality. In some cases access can be difficult, and in others many mechanical fuel modifications are simply not feasible (Weatherspoon, 1996). Mechanical treatment equipment is limited to moderate slopes, and other treatment techniques such as hand thinning and helicopter thinning are costly. This creates problems for strategic placement of fuel treatments, despite the fact that these areas might otherwise be good candidates (e.g., downslope of a densely populated location).

Pollet and Omi (2002) and Weatherspoon (1996) suggest that prescribed fire, as well as hand piling followed by jackpot burning, may be effective alternatives on slopes where mechanical treatment is not feasible. Safely using prescribed fire on steep slopes in LTB may therefore be relatively costly, and air quality concerns may severely limit burning, particularly on the west shore of the lake. However, these treatments may be overall less costly than suppression efforts and subsequent post-fire rehabilitation in the same areas if a severe wildfire is to occur.

Highlights

- Mechanical treatment equipment is limited to moderate slopes, and other potential techniques such as hand thinning and helicopter thinning are costly.
- Prescribed fire, as well as hand piling followed by jackpot burning, may be effective alternatives on slopes where mechanical treatment is not feasible

Adequacy of fire effects models

In order to evaluate fuel treatment effectiveness without treatment units being subjected to wildfire, managers need to accurately predict effects (e.g. tree mortality) in residual forest stands under a variety of weather conditions (e.g. 80th, 90th, 95th percentile fire weather). Fuel treatment performance is often based on what proportion of the residual stand will survive a wildfire under certain weather conditions. An example of the modeling process might be as follows. The residual stand is first classified in terms of fuel model and stand characteristics. These data are input into fire behavior models, such as those included in the software package FMAPlus (Carlton, 2004). With proper fuel model classification and weather conditions, FMAPlus can predict crown scorch height which, along with stand tree heights, species, and diameter at breast height (dbh) can be used to predict tree mortality, using models developed by Ryan and Reinhardt (1988). The Ryan and Reinhardt model is the basis for the tree mortality model currently used by the most common fire behavior and effects models used by managers in the USA, namely BehavePlus, First Order Fire Effects Model (FOEFM), and the Fire and Fuels

Extension to the Forest Vegetation Simulator (FFE-FVS) (Hood et al., 2007). The accuracy of these prediction efforts thus depends in large part on both the models themselves (fuel models, fire spread models, mortality models), and the inputs to the models.

Little work has been done specifically testing the adequacy and accuracy of fire effects models in the LTB. However, a recent study by Hood et al. (2007) examined post-fire mortality of the most common conifer species in the Western US after 21 different fires. The species examined included the dominant conifer species in the Lake Tahoe basin, including Jeffrey pine, ponderosa pine (Pinus ponderosa Laws.), red fir, white fir, incense-cedar (Calocedrus decurrens (Torrey) Florin), lodgepole pine and sugar pine (Pinus lambertiana Douglas). Predictions of individual tree and stand level mortality were made based on crown scorch volume and dbh (inputs to the Ryan-Reinhardt model), and were compared with actual mortality 3 years post fire. Results varied by species and fire, but pertinent to the LTB were the findings that model classification of individual red fir trees was among the least accurate by species. At the stand level mortality was generally overpredicted for red fir and incense-cedar. At the fire level, the model tended to overpredict mortality of yellow pines (ponderosa and Jeffrey). Overall, accuracy of individual tree mortality generally increased with increasing probability of mortality. They suggest that model accuracy could be improved by incorporating a variable quantifying stem injury, and by improved bark thickness equations. Accounting for local ground fuel consumption during prescribed fire can also increase model accuracy (Stephens and Finney, 2002). More accurate analysis of fire weather variability and fire behavior prediction inputs, such as more appropriate fuel models for masticated fuel beds, should also improve subsequent effects predictions for mangers designing fuel treatments.

Highlights

- The 1988 Ryan and Reinhardt model is the basis for the tree mortality model currently used by the most common fire effects models used by managers in the USA.
- In a recent study of post-fire mortality of the most common conifer species in the Western United States, the authors suggest that model accuracy could be improved by incorporating a variable quantifying stem injury, and by improved bark thickness equations.
- Additional accuracy may be gained by more accurate analysis of fire weather, more accurate fuel models, or better accounting for local ground fuel consumption in prescribed fire.

Scientific Information on Fire in the LTB

Given that Lake Tahoe is one of the treasures of the Sierra Nevada, there is remarkably little direct scientific information about an ecological process as important as fire. In addition, the challenges that climate change will bring require that we take action now to achieve a more sustainable coexistence with wildfire in the future (Moritz and Stephens, 2008). New fire-related research in the LTB is crucial to answer the questions put forth earlier in this paper.

One key tool in common with all of the questions at hand is the application of models for fire behavior and subsequent fire effects. Though various forms of mastication are becoming popular for biomass treatment in Sierra Nevada forests, relatively little data exists on post-treatment fire behavior and effects. Because we cannot examine these effects in a wildfire or ―worst case scenario" setting, the best option for predicting outcomes would be to have an accurate and well performing model for masticated fuels, including how these fuels decompose. Fire effects models exist for evaluating potential tree mortality after various fuel treatments, but these too require further development and testing for successful application in LTB. In order for any model predictions to be useful, a thorough understanding of local fire weather is also required, since this is what dictates the conditions under which treatments are expected to perform. The importance of fire weather data in LTB is highlighted by the fact that ―high severity" fire weather conditions were estimated to be only 19 km/h (12 mph) based on weather station data near where the Angora Fire burned last year (C.G. Celio et al., 2004). However, gusts of up to 48-64 km/h (30-40 mph) were recorded by weather stations and firefighters during the Angora Fire (Murphy et al., 2007). Improving our understanding of weather related to problem fires in the LTB, having accurate fuel models for new types of fuel beds, and improving fire effects models for species and forest types within the LTB will be vital as we plan to treat more and more of the landscape.

Two of the most difficult environments for fire management decisions – riparian areas and steep slopes – will probably continue to pose challenges in the LTB. Understanding the thresholds at which fire enters or is retarded by SEZs will help us to predict fire behavior and effects in riparian areas. This will also inform management as to whether leaving SEZs untreated is a viable management strategy, although tradeoffs in other important values will still need to be assessed. A similar situation exists concerning fuel treatments on steep slopes, and prescribed fire in these locations should be given greater consideration. In general, more extensive use of prescribed fire in the LTB will require that the benefits of restoring an important natural process and burning in relatively controlled circumstances be factored into a decision-making process that is relatively inflexible (e.g., regarding air quality).

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