Landscape Planning

Expectation and Evaluation of Fuel Management Objectives

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Abstract—*The success of fuel management in helping achieve wildland fire management goals is dependent first upon having realistic expectations. Second, the benefits of fuel management can be realized only when treatments are applied at the appropriate scale to the appropriate source of the problem(s). Scales range from the site- or stand-level to landscape-level, but apply differently for purposes of benefiting wildland values than for increasing home survivability. Lastly, accomplishing the broad goals for fuel management requires understanding how proposed treatments directly contribute to solving specific problems. This process of finding solutions to fire problems is framed in terms of "fire risk management" or reduction of "expected loss." This conceptually depicts the way that treatments can influence fire behavior and thus produce benefits by reducing losses and it avoids the unrealistic expectations that fuel management will stop wildfires and prevent homes from burning.*

Introduction

Fuel management is receiving increasing attention as a means of modifying wildland fire behavior and mitigating threats to the urban interface (National Fire Plan http://www.fireplan.gov/), including the Cohesive Strategy (http://www.fireplan.gov/cohesive_strategy_1_28_02.cfm) and 10-year Comprehensive Plan (http://www.fireplan.gov 10_yr_strat_pg_1.html). The rationale for treating fuels follows from:

1) recent and well publicized failures of fire suppression to protect wildlands and developed areas under extreme fire conditions (Colorado/Arizona/Oregon 2002, Montana/Idaho/Colorado 2000, California 1987), and
2) the realization that the extreme nature of these fires has sometimes been exacerbated by human modification of fuel conditions.

Large fires burning under extreme conditions of high winds and low humidity are difficult, if not impossible, to suppress. These extreme weather conditions are expected regularly during the fire seasons of the western United States. The prevalence of extreme fire behavior in low-elevation forests is, however, partly a consequence of effective fire suppression during the past century. Exclusion of historically frequent fire from these ecosystems has resulted in dramatic changes to vegetation structure and fuels compared to conditions in the 19th century (Wilson and Dell 1971; Arno and Brown 1989, 1991). These alterations of the fuel structure, specifically the in-growth of trees and accumulation of dead woody fuels, tend to readily support extreme fire behavior (crown fire, spotting). This reduces the effectiveness of fire suppression and creates uncharacteristically severe effects in those ecosystems compared to pre-existing ecological disturbance regimes. Management of these fuels directly is, therefore, seen as a proactive means to change fire behavior

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and effects (Brackebusch 1973; Davis and Cooper 1963; Kallender 1969; Koehler 1992; Martin et al. 1989; Wood 1982). The need for fuel management solutions has recently been made especially acute in these low-elevation areas because of human encroachment and development of areas formerly classified as wildlands.

Although the conceptual basis of fuel management is well supported by ecological and fire behavior research in some vegetation types, the promise of fuel management has lately become loaded with the expectation of a diffuse array of benefits. Presumed benefits range from restoring forest structure and function, bringing fire behavior closer to ecological precedents, reducing suppression costs and acres burned, and preventing losses of ecological and urban values. For any of these benefits to be realized from fuel management, a supporting analysis must be developed to physically relate cause and effect, essentially evaluating how the benefit is physically derived from the management action (i.e. fuel management). Without such an analysis, the results of fuel management can fail to yield the expected return, potentially leading to recriminations and abandonment of a legitimate and generally useful approach to wildland fire management.

In this paper, we seek to improve the performance and acceptance of fuel management by examining:

1) common expectations of fuel management effects and performance compared to reality,
2) some implications of recent research on fuel treatment scale, prescriptions, and locations, and
3) goals, objectives, and using the concept of “fire risk” to support and direct fuel treatment projects.

Expectations for Fuel Management

A number of false or exaggerated expectations are endemic to the general public and fire management organizations alike. The persistence of these expectations serves to hinder the proper use of fuel management because:

1) they suggest excessively high standards for the success of the fuel treatment,
2) the scope of application or benefits is too broad for a single fuel treatment technique, and
3) they transfer responsibility for fire losses or fire protection to the wrong people or place.

Some of these perceptions or expectations are listed in table 1 along with clarifications as to more realistic views.

Local and Lanscape Scales of Fuel Management

The process of developing specific objectives for fuel treatments and evaluating how treatments might perform necessarily requires an explicit consideration of spatial scale. Two basic scales can be identified with respect to the way that fuel management affects fire behavior. The *local scale* applies to fuel management efforts within a forest stand, a treatment unit, and next to and including a house or structure. Surface fuels removed by prescribed burning or canopy fuels removed by thinning change fire behavior within the local domain of the treatment unit. Many studies have shown that fire behavior

Table 1—Expectations of fire and fuel management compared to more realistic performance.

Expectation	Reality
Adding more firefighting resources will reduce acres burned	The reality is that fire suppression works except when it doesn't. Most fires are already successfully attacked (~96%) leaving the rest to burn under conditions too extreme for suppression success. More firefighting resources can be expected to change wildfire acreage very little because only a slim fraction (~4%) of fires currently escape. Furthermore, it makes little sense to increase fire suppression efforts to solve a fire behavior problem that is widely recognized as having been exacerbated by fire suppression effects on fuels.
Structures and homes will be protected by firefighting resources	Urban interface fires typically overwhelm resources because of the extreme conditions under which they occur (i.e., when fire suppression fails). Thus, exposure of dozens of structures simultaneously to fire brands and fire encroachment exceeds the capacity of existing suppression forces to protect and extinguish them. The problem is compounded in dense neighborhoods when structures start to burn or become fully involved because of their tendency to ignite adjacent structures.
Wildland fuel management prevents structure loss	Wildland fuel management changes wildland fire behavior. Structure loss (i.e., homes burning) is dependent on local properties of the structure and its immediate surroundings. This means that the proximate responsibility for structure loss from fire primarily resides with the private owners of the structure and immediate property, not with public land management agencies.
Fuel treatments will stop wildland fires	Fuel treatments change fire behavior within limitations of their prescription. That is, the design criteria or prescription of fuel treatments (see below) allows them to perform alterations in fire behavior up to a limit of weather conditions (primarily fuel moisture and winds). This change in behavior includes reduced intensities and spread rates, but does not prevent combustion. The changes in fire behavior and fuel conditions may enhance the effectiveness of fire suppression tactics, but it is impossible for fuel treatments alone to stop fires from burning or spreading.
Fuel management can be equally successful for all vegetation and fire regimes.	Fuel management can alter fire behavior but the longevity of these alterations and the ecological appropriateness of the treatment are specific to a given vegetation type. The most common fuel treatments today are concomitant with forest restoration of low-elevation pine and mixed-conifer forests. The same ecological justification and desired changes in fire behavior are inappropriate models for fuel hazard reduction in grasslands that recover following a single growing season or to high-elevation forest characterized by stand-destroying fire regimes. Fuel management strategies and ecological rationale are required for each fire regime and vegetation community.

responds at this local scale to fuel management measures (Helms 1982; Martin et al. 1989; Deeming 1988; Pollet and Omi 2002). This scale, and only this scale, corresponds to the physics of home ignition, whether from firebrands or flames impinging upon home construction materials (Cohen 2000b). The physical properties of the home and its immediate surroundings determine ignition potential and are restricted to the structure and material in very close proximity as determined by principles of radiation and convective heat transfer.

The other scale is described here as the *landscape scale* when concerning wildland areas, or the *community scale* with respect to urbanized environments. This broad scale is a collection of elements from the local scale. That is, wildland landscapes are composed of many stands and treatment units whereas communities are composed of various combinations of structures and undeveloped lots. Many wildland fires are almost an archetypal landscape process because they are larger than a single stand or structure and they move over, across, and through the collection of smaller scale elements like forest stands and homes. Thus, the fire behavior at these broader scales involves the topology or spatial arrangement of stands and homes, each affecting the fire at its own local scale. This spatial arrangement of stands and homes is crucial to determining the success of fuel management activities in changing effects of large fires either at the local or landscape scale. Individual treatment units, regardless of their shape or position, will be irrelevant to the progress and behavior of the fire at the landscape scale unless the spatial nature (topology) of treatment arrangement is considered.

Stand Level Prescriptions for Fuel Management

Fire behavior responds to fuels, weather, and topography. Changes to fuels, for example from prescribed burning or thinning, are related to potential fire behavior at that site and have resulted in reduced severity of wildfires where fuel treatments have occurred (Martin et al. 1989; Helms 1979; Agee 1998). For many fuel management objectives, the goal is to limit surface fires from becoming crown fires. To design a fuel management prescription within a treatment unit, prescription elements must specify changes to specific fuel attributes. These fuel attributes must be connected to a desired change in fire behavior through some physical mechanism. Such a physical mechanism relating surface and crown fires was described by Van Wagner (1977, 1993). His formulation identifies two thresholds that define crown fire activity. Crowns are ignited after the surface fire reaches a critical fireline intensity relative to the height of the base of the aerial fuels in the crown. This crown ignition can become an "active" crown fire that spreads much more rapidly through the crowns, if its spread rate is high enough to surpass the second threshold based on the crown bulk density (kg m^{-3}). Thus, Van Wagner's (1977) relationships suggest that fuel management prescriptions can limit crown fire activity by first reducing surface fuels to limit fireline intensity, then thinning the smallest trees or pruning to elevate the base of aerial fuels from the ground surface. A final measure may involve crown thinning (removal of some canopy level trees) to make difficult the transition to active crowning. This linkage between surface and crown fire has been described by Scott and Reinhardt (2001) and provides a method for determining stand-level prescriptions for fuel management.

Landscape Level Treatment Planning

Fire and fuel managers are familiar and generally comfortable with developing prescriptions for individual stands, whether for silvicultural purposes, forest restoration, or wildland fuels treatment as described above. However, an individual stand treated to a given prescription will probably be irrelevant to fire behavior and effects at the landscape scale because wildfires are often larger than individual treatment units (Salazar and Gonzalez-Caban 1987; Dunn 1989). Thus, some means of spatially organizing treatment units must be considered in order to accomplish the landscape level goals for fuel management. Brackebusch (1973) suggested large-scale frequent mosaic burning. Another landscape strategy described by Finney (2001) seeks specifically to disrupt fire growth and modify fire behavior rather than to stop fires since the latter is not realistic (see Expectations above). Strategic area treatments (Finney 2001; Hirsch et al. 2001) create landscape fuel patterns that slow fire growth and modify behavior while minimizing the amount of treated area required (figure 1). Similar ideas in forest management have been developed to achieve spatial harvest objectives (Baskent and Jordan 1996; Baskent 1999). The impetus follows from limitations on the amount and placement of fuel treatments because of land ownership, endangered species, riparian buffers, etc. It has precedence in the way that natural fire patterns serve to fragment fuels across landscapes to produce self-limiting fire growth and behavior as shown in Yosemite National Park (van Wagtendonk 1995), Sequoia National Park

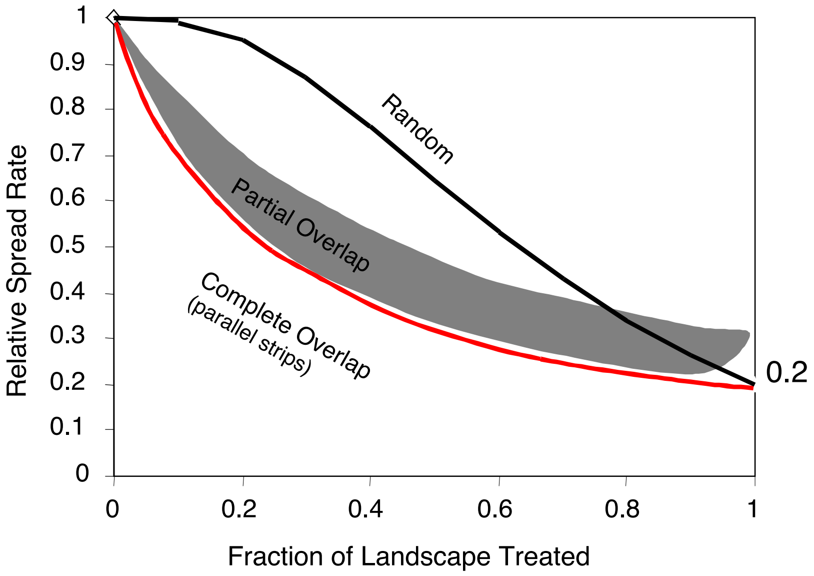

Figure 1—Overall fire spread rate as a function of treatment fraction for different spatial patterns of treatment units (from Finney 2001 and Finney 2003, treatment assumed to reduce spread rate to 0.2 of the untreated fuels). Compared to patterns that require overlap among treatments, the random treatment pattern produces little reduction in overall fire spread rate until relatively large proportions of the landscape are treated (because fire goes around the treated patches).

(Parson and van Wagtendonk 1996), and Baja California (Minnich and Chou 1997). Landscape analysis of fire behavior and spread patterns is now prompting research into computer software for optimally locating fuel treatments for slowing fire growth and limiting effects (figure 2).

A frequently proposed alternative to this strategic landscape approach involves the fuel break concept (Weatherspoon and Skinner 1996; Agee et al. 2000). The stated purpose of fuel breaks is to reinforce an existing defensible location for use by fire suppression forces in stopping fire spread (Green 1977).

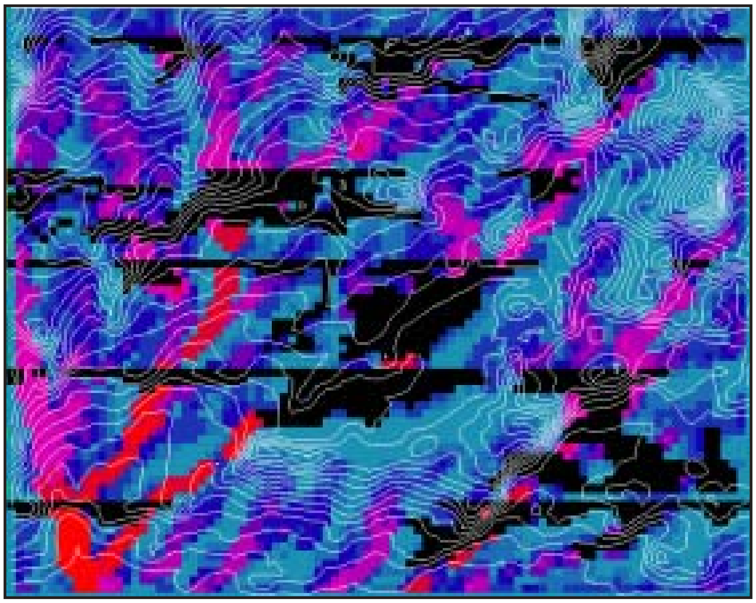

Figure 2—Routes resulting in the most burned area can be identified using graph theory (Finney 2002). These routes reflect the greatest opportunities for disrupting the simulated fire growth using fuel management. Red indicates high influence and blue little or none. Heuristic algorithms can then optimize fuel treatment locations (shown in black) that result in efficient reductions in fire spread rate per unit area treated. The treatments shown in black reduce fire spread rate by 40% with less than 16% of the area treated because treatments are located to block the fastest and most influential routes.

The putative benefits of fuel breaks are achieved when undesirable fire effects are avoided by holding fires to smaller sizes. No change in behavior or effects is achieved away from the fuel break or if fuel breaks fail to stop fires. Thus, fuel break performance and benefit is based on the questionable expectation that fire suppression will be capable of "stopping" fires after initial attack fails (see Expectations above). Large fires escape initial attack for many reasons that include resource scarcity due to high numbers of ignitions, and spotting and crown fire behaviors that make holding a pre-defined position by firefighters untenable and perhaps dangerous. Furthermore, the only firefighting tactics supported by fuel breaks are categorized as "indirect" (Brown and Davis 1973). This means that the rest of firefighting tactics (direct attack and parallel attack) are not enhanced regardless of the current fire behavior or fire position on the landscape relative to the location of the fuel break. A large fire that slows before reaching a fuel break (because of a change in weather conditions, nighttime, etc.) must be attacked (by direct or parallel tactics) with no benefit of the fuel break. Utilizing fuel breaks involves a large burnout operation, which may be of a size equal to the original wildfire, take place regardless of the fire behavior at its current location, and produce negative effects on wildland vegetation greater than the original wildfire. Maintenance costs of fuel breaks are often ignored by proponents but maintenance is a perpetual burden that is likely to divert efforts from managing fuels and vegetation on the remaining majority of the landscape.

Structure Ignition

Research findings indicate that a home's characteristics and the characteristics of a home's immediate surroundings within 30 meters principally determine the potential for wildland-urban fire destruction. This area, which includes the home and its immediate surroundings, is termed the *home ignition zone*. The home ignition zone implies that activities to reduce the potential for wildland-urban fire destruction can address the *necessary* factors that determine ignitions and can be done *sufficiently* to reduce the likelihood of ignition. Wildland fuel reduction outside and adjacent to a home ignition zone might reduce the potential flame and firebrand exposure to the home ignition zone (i.e., within 30 m of the home). However, the factors contributing to home ignition within this zone have not been mitigated. Given a wildfire, wildland fuel management alone (i.e., outside the home ignition zone) is not sufficient nor does it substitute for mitigations within the home ignition zone.

The home ignition zone applies to a single home as well as a neighborhood of homes in proximity. The fire physics and the requirements for ignition do not change with increasing housing density, but the social response changes. Homes in areas where the home ignition zone falls within property boundaries can largely be addressed as individual homes without interaction with other homes. As densities increase and home ignition zones extend across property lines, the ignition potential of the home ignition zones depend on the activities of more than one property owner. At higher housing densities more than one house can fall within a home ignition zone. In such cases a neighboring house burning may become a flame and firebrand source for igniting adjoining homes. When homes share home ignition zones, the wildland-urban fire problem must become a collective, community effort. Wildland-urban fires such as Panorama (San Bernardino, CA 1980), Baldwin Hills (Los Angeles, CA 1985), Oakland (Oakland, CA 1991), and Laguna (Laguna, CA 1993) indicate that communities that do not act collectively to reduce their home ignitability have a high potential to burn collectively.

These findings were based on a diverse research approach utilizing modeling, experiments, case studies, and wildland-urban fire investigations. The model calculations were made on the assumptions of intense fire conditions (e.g., crown fire) and ideal heating characteristics (flames radiating as an ideal radiator, a black body). Model estimates of direct flame heating indicated that wood ignition would not occur during the burning duration of crown fire flames at distances greater than 30 meters (Cohen 2000a). Experiments were conducted to check the results of the modeling. The experimental crown fires provided radiation and convection heating as well as firebrands capable of numerous spot fire ignitions. Home ignition studies during the International Crown Fire Modeling Experiment (Alexander and others 1998) showed that wood walls only ignited at distances from the crown fires closer than 20 meters. Wood walls at 20 and 30 meters did not ignite or significantly scorch. The home ignition experiments indicated that model calculations over-estimated the distance at which a wood wall would ignite (Cohen 2000a). Two former case studies analyzed home survival during severe wildland-urban fires. The case studies found that 85 to 95 percent home survival largely depended on two factors—a nonflammable roof and vegetation cleared within 10 meters of a home (Howard and others 1973; Foote 1994). Investigations of severe wildland-urban fires indicated that home destruction was not necessarily caused by the nearby flames of the intense crown fires; less intense surface fires spreading to the home or direct ignition from firebrands ignited the homes. Investigations also revealed severe wildland-urban fire destruction associated with nearby low intensity surface fires (Cohen 2000b) as well as surviving homes (without protection) surrounded by intense crown fires (Cohen in process). The possible associations between wildland fire behavior and home survival can be displayed in an association matrix (figure 3). Because homes survive high intensity fires and are destroyed in low intensity fires (Cohen 1995; Cohen and Butler 1998; Cohen 2000a; Cohen 2000b; Cohen 2001) it is questionable whether wildland fuel reduction activities are necessary and sufficient for mitigating structure loss in wildland urban fires.

		HOME SURVIVAL	
		yes	no
LOW WILDLAND FIRE INTENSITY	yes	y,y expected	y,n unexpected
	no	n,y unexpected	n,n expected

Figure 3—An association matrix depicts the assumed relationship between wildland fire intensity and home survival. The frequency with which combinations (y,n) and (n,y) have been observed supports the results of physical modeling in questioning the dependency of home survival on wildland fire behavior and fuel management conducted in wildlands.

Goals and Objectives of Fuel Management

The purposes of national fuel management activities in the United States are described by the broad goals stated in the National Fire Plan. These policy documents identify general goals for fuel management activities as:

1. Reduce risk of catastrophic fire
2. Protect communities
3. Reduce fuel hazards
4. Reduce wildfire acres and costs
5. Restore fire-adapted ecosystems

While adequate to express general directions for national fuel management policy, these statements are not intended to provide specific guidance to field-level fuel treatment projects. The "field-level," for this paper, describes the organizational level (e.g., USFS district) where specific fuel treatment units are identified and landscape planning is performed. This is the critical level that determines the success or failure of fuel management where the "rubber meets the road" and the fire meets the fuels. In other words, the success of an entire national policy hinges on the success of fuel treatments accomplishing the field-level benefits promised and expected.

If the broad policy goals are to be used to guide field-level projects, a set of specific objectives must be developed to justify field-level fuel treatment plans. These objectives must be based on a local problem analysis and have standards for evaluating the success or failure of the project. The following are steps that can help bring these broad policy-oriented goals down to specific objectives that permit treatments to be designed, evaluated, and justified:

1. Identification of the specific problems to be addressed by fire/fuel management.
2. Identification of the cause of these problems as relating to fuels or fire behavior.
3. Description of the desired outcome of the treatment measure (i.e., how much change is needed).
4. Identification of the appropriate scale of treatment needed to effectuate the desired outcome.
5. Description of the specific cause and effect relationship between the desired outcome and the proposed treatment(s).

Despite the apparent differences among the general policy goals, the field-level problems associated with them are almost identical. All deal with fuels and the dynamics of the local ecosystems, potential fire behavior, and the likelihood of undesirable effects of fire on urban and wildland areas (costs, losses, expenses). This suggests that the broad policy goals are so closely linked that a unified means of describing this linkage would facilitate understanding how to accomplish all of them. We suggest that all of these goals can be collapsed into the single broad category of "fire risk management." As the term suggests, fire risk is managed, not eliminated. That is, we don't eliminate natural disturbances, we mitigate the associated human disasters.

"Fire Risk Management" and Expected Loss

Risk is a word commonly used to describe threats from fire but it suffers from ambiguous meaning. The absence of a consistent and precise definition of "risk" hinders communication and, more importantly, the possibility of actually achieving a reduction in fire "risk" through fuel management. In other words, "*You can't do what you can't say.*" Historically, risk was used for fire prevention and was equated to the probability of a fire starting (Brown and Davis 1973). These data could be obtained from historical records for a local jurisdiction and partitioned according to location and cause. Although relatively easy to measure, this component has little to do with more critical questions concerning whether the fire once started would achieve a given size, burn a particular area, or cause a particular effect. The probability of burning and consequence of burning are far more relevant to the business of fuel and fire management than the probability of fire starts, but are completely different with respect to the method of calculating or estimating them.

Outside the realm of wildland fire management, risk is often expressed in terms of *expected loss.* Insurance companies calculate the expected loss of a home ($/year) so that the owner's premium can be determined. Despite the vagueness of its colloquial usage, "risk" defined as an expected loss has an exact mathematical formula involving the product of two numbers: 1) the probability of the event, and 2) the value change in the property because of the event. Wildland fires don't necessarily result in loss or negative consequences, so a more appropriate term would be *expected net value change*. Wildland fires have many different behaviors (e.g., intensity, spotting) that can produce value changes (e.g., fuel reduction, tree mortality, sedimentation of watersheds, structure damage). Since fire behaviors vary in place and time, there would be a distribution of behaviors and a distribution of corresponding changes in value (benefits and losses). In other words a theoretical expected net value change (E_{nvc}) from a wildland fire at a given location on the ground could be obtained for all *N* categories of a given fire behavior:

$$E_{nvc} = \sum_{i=1}^{N} p(F_i)[B_i - L_i]$$

where F_i is a given fire behavior (e.g., fireline intensity, firebrand density) and B_i and L_i are the respective *benefits* and *losses* resulting from that fire behavior (e.g., dollars from structure loss or tree mortality). Benefits and losses can be combined into a single net value change, but separating the terms in this equation emphasizes the importance accounting for potential benefits of some wildland fire behaviors to some wildland values in addition to losses. Note that $p(F_i)$is the probability of the i^{th} category of the fire behavior occurring and B_i and L_i are the respective benefits and losses for the i^{th} fire behavior category. This kind of equation would apply separately to each value of concern and related fire behavior(s).

To apply the expected value change to wildland fires, research is required to find ways to estimate the parts on the right hand side of the equation. The first part $p(F_i)$ (probability distribution of fire behavior) is particularly challenging because wildland fires are spatial and dynamic, occurring at different places and times and burning over space and time. A brute-force approach to calculating wildland fire probabilities would entail estimating fire growth across the landscape from every ignition point on a landscape, for every ignition date and sequence of weather, for all possible fire seasons and suppression responses. A given cell or node on the landscape would burn differently by backing, flanking, and heading fires depending on the relative location of the ignition and ensuing spread. Each cell or node on the landscape would thus have a probability distribution of fire behaviors represented by $p(F_i)$ in the equation above. The second parts B_i and L_i of E_{nvc} would then need to be determined for each fire behavior in the distribution (e.g., dollars lost for a specified level of fireline intensity). Some fire behaviors cause benefits to some values (e.g., fuel reduction, ecosystem health) but others can result in a total loss. That is the reason that fire expected loss would be the product of two probability distributions, one for the fire behavior and one for the net change in value (benefits minus losses) resulting from that fire behavior. If E_{nvc} could be calculated for all values, then their sum at a given site and over an entire landscape would provide maps that spatially ordinate "risk." These would be spatially sensitive to all scales of fuel management, from the local properties of structures to landscape-level fuel treatments. If ecological modeling and forecasts can be made of future landscape conditions, then cumulative E_{nvc} up to a given future date can be estimated, permitting tradeoffs and opportunity costs to be compared for different action plans. Only then will it be possible to examine the long-term ramifications of today's action or inaction, which very likely will be different from the short-term effects.

Although complicated and difficult to calculate, this mathematical definition of fire risk as an expected value change clearly demonstrates the ways that wildland and urban fuel management activities influence the components of fire risk. Fuel management in wildlands changes the probability that wildland fires move across the landscape, and whether they ultimately impinge on urban areas containing structures, or result in fires of different sizes and ecological effects. Thus, wildland fuel management changes the first part of the equation in terms of probability of a fire reaching a given location. It also changes the distribution of fire behaviors and ecological effects experienced at each location because of the way fuel treatments alter local and spatial fire behaviors (Finney 2001). The probability that a structure burns, however, has been shown to depend exclusively on the properties of the structure and its immediate surroundings (Cohen 2000a). This means that construction materials and their condition at the time of fire exposure that abate ignition from firebrands or flames change the second part of the risk equation only (e.g., replacing wood shingle roof with asphalt shingles changes the structure response to fire behavior). Changes to the flammable materials immediately surrounding the house affects the fire behavior distribution in the first part of the risk equation. Thus, fire risk as E_{nvc} can be improved for wildland and urban areas by:

1. Changing wildland fuels for a "fireshed" involving a wide area around the community (for many miles that include areas that fires can come from). This changes probability of fire movement and skews the fire behavior distribution by increasing the relative frequency of milder behaviors.
2. Treating fuels and reducing fire behavior immediately adjacent to the structures. This changes the fire behavior relevant locally to the ignition of structures.
3. Changing the properties of the structure. This improves its response when exposed to a given fire behavior.

The formulation of E_{nvc} also implies that risk is completely eliminated (goes to zero) when values vanish (total value and value change). This means that human systems of valuation are really at the heart of the idea of risk. There would be no expected loss if humans didn't exist, humans placed no values on wildlands or developed property, or the values didn't change as consequence of fire. More importantly, this shows that both the causes of risk and the solutions to risk reduction lie with human beings, not wildlands or natural dynamics. That is, a change of human perspective can make problems appear or disappear without changes in biophysical reality. The importance of human values in E_{nvc} also suggest the possibility that the necessarily long-term (multi-decade) management solutions based on E_{nvc} (if it could even be calculated) could be outdated by changing social and political values during those time periods.

The concept of expected net value change in managing fire risk encompasses all of the broad policy goals detailed above. Community protection as a goal expresses the desired reduction in expected losses and maximizing expected benefits (maximize E_{nvc}). Reducing fuel hazards involves local- and landscape-scale fuel modifications that limit fire behavior and thereby diminish the losses ($p(F_i)* L_i$) and increased ecological benefits ($p(F_i)* B_i$). Reducing fire suppression costs and wildfire acres is produced by changes in the probability distribution of fire sizes brought about by landscape fuel management and reduced duration of extended attack and difficulty with suppressing smaller and less extreme fires. Ecological restoration may also be addressed as diminished fire behavior, reduced losses of ecological values, and increased sustainability of ecosystems that are properly managed. Lastly, it is likely that quantitative assessment of E_{nvc} would lead to more realistic perspectives and expectations for the effects of fire and fuel management activities because alternative management scenarios could be compared and interpreted based on a common methodology.

Community Protection

As an example of how the components of risk management apply to the above policy goals, we can look at the term "community protection." The term community protection is one of the most widely and prominently stated goals for fire and fuel management. A community is really a collection of many tangible and intangible parts that are held in common, including both developed areas and wildland areas:

1. Structures, neighborhoods, businesses
2. Infrastructure (roads, bridges, rivers, dams, airports)
3. Lifestyle and economy (recreation, agriculture, extractive industries like logging, mining)
4. Environment (scenery, air quality, wildlife, natural hazards like fire, earthquakes, hurricanes)

Such diverse community values makes it difficult to justify any single overt fuel management tactic on the basis of "protecting" all aspects of a community from wildland fires. Protection afforded to one component by a given tactic (for example, localized fuel management for structure protection) may little benefit other values (like scenery, air and water quality, or recreation opportunities). The expected loss concept suggests that treatment tactics must be partitioned according to their specific fire behavior changes that are appropriate and relevant to the response of the values concerned. That means essentially treating wildlands separately from developed areas because the effects and scales of those effects are not uniformly applicable.

To benefit the urban portions of a community, fuel management research suggests that fuel management activities need only be concerned with the fuels in the immediate proximity of the structures – within their ignition zone. The material properties of the structures themselves are also important, and managing fuels within the home ignition zone is shown to be the most effective at reducing the nearby sources of firebrands and combustible fuels and vegetation that are commonly associated with structure ignition. When fires occur, structures are less likely to be "lost," thus reducing the expected net value change of the urban values.

Wildland fuel management in low-elevation forest types, extending perhaps many kilometers away from urban locations, however, is critical to reducing the likelihood that wildland fires will spread to urbanized areas and pose ignition threats. Wildland fuel treatments can reduce the probability portion of the expected net value calculation by changing fire behaviors at long distances as well as fire movement. These changes in fire behavior increase the effectiveness of fire suppression, especially during initial attack by slowing fire growth and limiting spotting. They also increase the survivability and resilience of low-elevation forest vegetation to the inevitable wildland fire, thereby benefiting the wildland values of the community. Because urban fire disasters often result from wildland fires igniting tens of kilometers away from urbanized areas under extreme weather conditions (e.g., the Hayman fire in Colorado and the Rodeo-Chedeski fires in Arizona in June 2002), wildland fuel management activities must be located broadly across those landscapes. Evidence that fuel breaks surrounding urban zones are sufficient to reduce threats to urban values is lacking. Because of their location on the periphery of wildlands, fuel breaks cannot reduce losses of wildland values associated with a community. Although it is commonly argued that fuel breaks will reduce wildfire intensities adjacent to residential development and thereby allows firefighters to protect homes, wildland-urban fire disasters tend to occur during severe fire conditions when fire behavior characteristics often overwhelm fire protection resources. These fuel treatments may facilitate firefighter effectiveness but only if firefighters are available to be effective. Given homes with high ignition potential and without fire protection, even a low intensity wildfire can result in severe wildland-urban fire destruction as exemplified by the 2000 Los Alamos fire destruction (Cohen 2000b).

In the context of fire risk management, the general goal of “community protection” can only be accomplished if treatments satisfy the principles of being *necessary* and *sufficient* for the specific elements of the risk equation. Wildland fuel management is *necessary* to change wildland fire behavior ($p(F_i)$), but to be effective at mitigating risk for landscape-level community values and adjacent developments it must be accomplished in *sufficient* amounts and patterns. Wildland fuel management is, however, not *sufficient* alone to abate threats to home ignition. Susceptibility of homes to damage involves different factors than wildland resources (e.g., construction standards vs. tree species) and relates to different fire behaviors than do wildland resources (e.g., firebrands vs. fireline intensity). To reduce expected loss from home ignition, it is *necessary* and often *sufficient* to manage fuels only within the home ignition zone (change $p(F_i)$) and abide by fire resistant home construction standards (change L_i).

Conclusions

We suggest that problems to society posed by wildland fires are analogous to those of traffic accidents. Traffic accidents cannot be stopped, either by increasing the police force, or by reducing speed limits. No government agency or politician believes it possible to stop them altogether. The consequences of traffic accidents that do occur, however, can be mitigated by engineering safety features into automobiles (airbags, seatbelts, frame design) as well as transportation infrastructure (modifying bridge abutments, steep curves, etc.). Likewise, wildland fires cannot be stopped, either with an increasing firefighting budget or fire prevention efforts. Wildland fires will always occur, and ecologically, we know that they must occur in many ecosystems; excluding them is not desirable even if it was possible. The challenge for fire management is to reorient the focus of efforts toward limiting the undesirable effects of fires on ecosystems and human development, not stopping fires. Similar to traffic safety engineering, this paper describes approaches to engineering wildland landscapes and home ignition zones that make our societies more compatible with wildland fires. Sustainability of wildland ecosystems can be accomplished by managing fuels and landscape pattern to change fire behavior. Structure survival can be greatly increased by separate efforts that adopt readily available construction standards and maintain fuel conditions in the home’s immediate vicinity. Expectations of our society must also become aligned with the reality of coexistence with fire and its positive and negative effects.

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