

CHANGES TO SIMULATED FIRE BEHAVIOUR AND SOCIETAL BENEFITS AFTER TWO LEVELS OF THINNING IN A MIXED-CONIFER WILDLAND-URBAN INTERFACE COMMUNITY

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Potential fire behaviour and various societal benefits (air pollution removal, carbon sequestration, and stormwater runoff) were quantified in a California Sierra mixed-conifer forest in (a) untreated conditions, (b) after removing all understorey trees <15 cm dbh, and (c) after thinning 50% of the stand's total basal area. Potential fire behaviour was modelled under constant conditions near a hypothetical development by the FARSITE fire behaviour and growth simulator and societal benefits were calculated by CITYgreen, both GIS-based software applications. Results showed that fire behaviour was considerably moderated by both thinning treatments. Modelled societal benefits, however, were largely unaffected by either treatment, which may be the result of inherent assumptions in the model. Critical elements of sustainable development in the wildland-urban interface are discussed, including fuels management, enforceable construction standards, sound land-use planning, community education, and appropriate suppression resources. Each of these components will vary depending on the ecosystem and socioeconomic conditions of a given area that is under consideration.

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California, more than any other region of the United States, illustrates the increasing challenges of fire management in the wildland-urban interface (WUI). A burgeoning population who lives amongst a menagerie of volatile vegetation types is increasingly leading to extensive costs and losses associated with wildfires. Vegetation in California is largely a product of a Mediterranean climate, where a mild rainy season is followed by periods of up to 8 months of drought. Therefore, both live and dead fuel moistures are regularly at critical levels for extreme fire behaviour. Additionally, high-intensity foehn winds are common on the central and southern coasts of California during the driest months of the year, contributing to the size and intensity of fires in the area. Further, in many montane forests in California and throughout the western United States, a century of fire exclusion has led to vast levels of overstocking, leading to extremely high fuel loading and continuity.

Fourteen fires in California have burned over 40,000 ha, including the 2003 Cedar Fire in San Diego County, which burned over 105,000 ha (California Department of Forestry & Fire Protection, 2007a). While similar sized fires may be experienced elsewhere, the immense population in California,

currently 35 million and expected to grow to 46 million by 2030 (California Department of Finance, 2004), leads to losses unlike most parts of the world. For example, 14 fires have consumed over 300 homes there, again led by the Cedar Fire, which consumed 4847 structures (California Department of Forestry & Fire Protection, 2007b). Of greatest concern is that 7 of the 9 most destructive fires in California have occurred in the last 20 years. Given demographic trends of continued immigration to wildland areas, most feel that the trend of highly destructive fires will continue largely unabated in the foreseeable future.

In addition to immediate fire effects, wildfires in California are regularly followed by mudslides and immense sediment deposition into streams and estuaries, which significantly degrade public safety and environmental quality. For example, a mudslide following the 2003 Old Fire on the San Bernardino National Forest killed 14 people. And the 1994 Highway-41 fire on the Los Padres National Forest caused accelerated erosion into the Morro Bay National Estuary, leading to lowered taxonomic diversity there for several years (U.S. Environmental Protection Agency, 1995).

Therefore, it is imperative that agencies tasked with wildland fire management develop efficient and effective management strategies in the WUI, which should vary by site dependant on the biophysical and socio-political factors present. Unfortunately, it seems that many fire managers in the United States regularly think of vegetation simply in terms of fuels and potential fire behaviour, overlooking the many tangible benefits that vegetation provides. Such societal benefits in the WUI could include reduced home cooling costs and air pollution (Taha *et al.*, 1997), lessened need for stormwater runoff infrastructure (Sanders 1986), increased carbon sequestration (Rowntree and Nowak, 1991), wildlife habitat, and others. Thus, to best insure sustainable development in the wildland-urban interface, site-specific vegetation management plans must be developed that minimises fire risk while simultaneously maximizing the benefits that distinct vegetation communities provide.

Currently, no such single instrument exists to assist fire managers in developing fuel modification prescriptions to maximise both elements. However, existing software packages that examine each element individually could be used to facilitate effective and environmentally responsible prescriptions. Fire behaviour modelling programs such as BehavePlus (for surface fire behaviour), NEXUS (for crown fire potential), and FARSITE (for fire spread across landscapes) could be used in conjunction with CITYgreen or other programs that quantify specific societal benefits. The results could then be used to derive a plan that simultaneously minimises fire behaviour while maximising benefits that vegetation bestows.

The principal objective of this manuscript is to illustrate how various treatments simultaneously affect fire behaviour and societal benefits using two GIS-based software packages commonly used in the United States. Specifically, the author explores how modelled fire behaviour and various societal benefits change in a California Sierra Nevada mixed-conifer forest after two levels of thinning intensity. Further, elements critical to sustainable development in the WUI are explored. While centric to California, it is hoped that the successes and lessons learned there can be applied to similar regions of the world.

MATERIALS AND METHODS

A hypothetical WUI community was created to illustrate the potential effects of thinning on fire behaviour (Fig. 1). In the hypothetical scenario, a common ignition point for all fire behaviour simulations was located below a subdivision of homes, which set higher atop a ridge. The untreated landscape largely consisted of dense, mixed-species stands of conifers having a high degree of vertical continuity, which would likely facilitate torching and active crown fire spread via spotting. Indeed, 95% of the surface fuel models across the landscape consisted of dry climate timber-shrub types (Timber Understorey models per Scott & Burgan, 2005). Two fuel treatments were implemented across the landscape, including thinning all trees under 15 cm (Understorey Removal), and thinning-from-below to 50% of the total stand basal area (Thin to 50% BA). For each fire behaviour simulation, all inputs were held constant except canopy base height and canopy bulk density, the values of which were input across the landscape for a given simulation per Scott and Reinhardt (2005) for identical treatments in Sierra Nevada Mixed Conifer (Table 1).

Assuming constant conditions (Table 2), FARSITE (Fire Area Simulator v. 4.1.03) was utilised to model fire spread for 10 hours from a single, common ignition point before and after each treatment was implemented throughout the landscape. Community benefits of air pollution removal (ozone, SO₂, NO₂, CO, and particulate matter), carbon sequestration, and stormwater storage capacity were calculated by CITYgreen for ArcGIS. CITYgreen vegetation classifications were input across the landscape by converting fuel model raster data utilised by FARSITE to an appropriate CITYgreen "feature". In all simulations, the grassland areas were classified in CITYgreen as "Open Space - Grass/Scattered Trees>>Grass cover > 75%". The forested areas were classified as "Trees>>Forest litter understorey>>No grazing, forest litter and brush adequately cover soil" in the untreated landscape, "Trees>>Forest litter understorey>>Grazed but not burned, some forest litter" after the Understorey Removal treatment, and "Trees>>Forest litter understorey>>Forest litter and brush destroyed by grazing or burning" after the Thin to 50% BA Treatment.

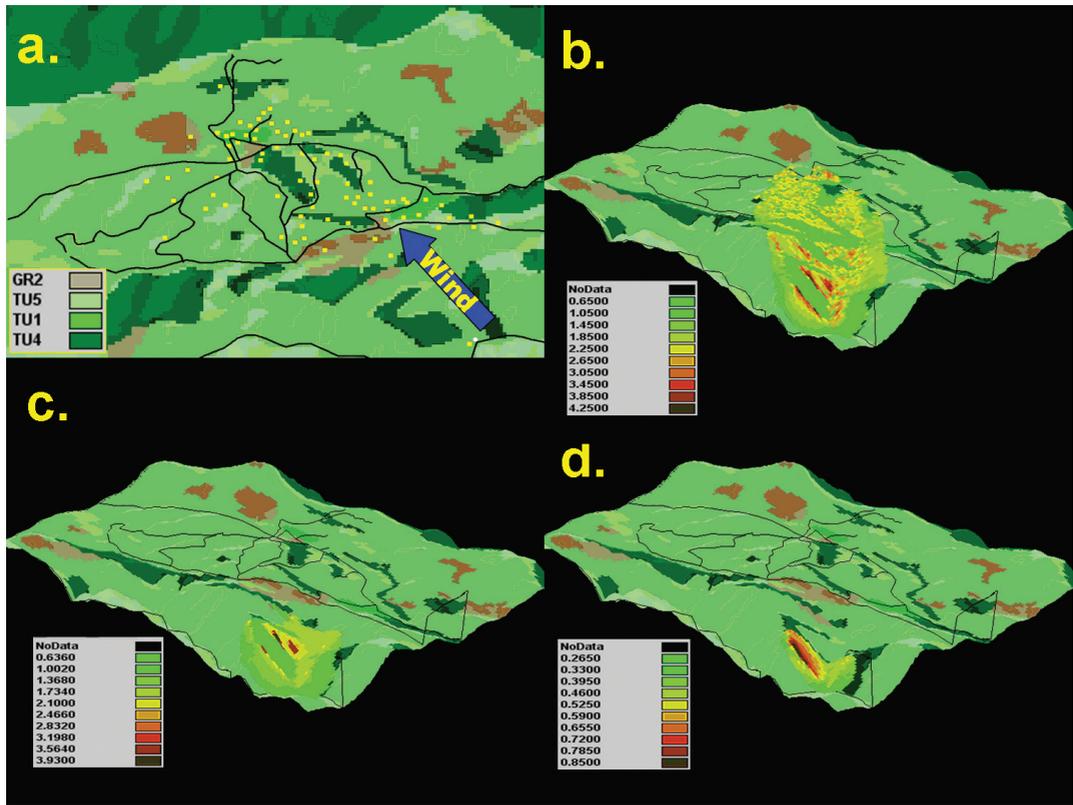


FIG. 1. [a] Wildland-urban interface community in a Sierra Nevada mixed-conifer forest (yellow squares = houses), and simulated fire boundary and flame length (m) after 10 hours [b] without treatment, [c] after understorey removed (<15 cm dbh), and [d] thinned to 50% basal area. Varying colors across landscape designate fuel models (see inset in ‘a’ for specific fuel models per Scott and Burgan (2005)). Varying colors within fire boundaries designate flame length (see inset in ‘b’-‘d’ for specific flame lengths).

TABLE 1. Canopy characteristics of a Sierra Nevada mixed-conifer forest in an untreated landscape, after removing all understorey trees <15 cm, and after thinning from below to 50% of the initial stand basal area.

<u>Simulation</u>	<u>Stand ht (m)</u>	<u>Canopy Base ht (m)</u>	<u>Canopy bulk density (kg/m³)</u>
Untreated	34	2	0.101
Understorey Removal	34	4	0.101
Thin to 50% BA	33	11	0.037

RESULTS

Both flame length and area burned were substantially reduced during the 10-hour simulation after both thinning treatments (Fig. 1). In the untreated landscape, the simulated fire burned 203.5 ha, but was reduced to 76.3 ha in the Understorey Removal treatment and 63.9 ha in the Thin to 50% BA treatment.

While thinning substantially impacted simulated fire behaviour, the calculated societal benefits were largely unaffected by either treatment (Table 3). Indeed, there were no detectable differences in either pollution removal (179 t for all simulations) or carbon sequestration (1,294 t for all simulations) between any of the scenarios. Further, stormwater storage capacity changed only slightly between treatments, ranging from 219,768 m³ in the untreated landscape to 170,754 m³ in the Thin to 50% BA treatment.

DISCUSSION

Both thinning treatments considerably reduced simulated spread rate and flame length in the untreated landscape. This reduction is apparently the result of an increase in canopy base height (from 2 m to 4 m) and not a reduction in canopy bulk density. Increasing the intensity of thinning had

minimal effect on fire spread because the greater canopy base height after either thinning discouraged torching and subsequent lofting of embers ahead of the main fire front, thereby limiting fire spread and intensity. Because few trees torched after raising the canopy base height, further reducing the canopy bulk density in the more intense Thin to 50% BA treatment (from 0.101 kg/m³ to 0.037 kg/m³) had minimal impact to simulated fire behaviour. Managers, however, might still consider the more intense thinning in order to generate revenue from the sale of larger trees so as to recover costs incurred in a non-commercial Understorey Removal treatment.

Although thinning significantly impacted fire behaviour, the societal benefits derived from the vegetation changed very little. Indeed, the only change to calculated benefits was a slight reduction in the stormwater storage capacity afforded by the vegetation. The absence of significant change seems likely due to an over-reliance on overstorey canopy coverage, which is assumed constant for a given vegetation type, as CITYgreen's primary variable when calculating most benefits. Thus, even though total vegetation would obviously decline after thinning, the program does not

TABLE 2. Landscape characteristics and FARSITE inputs used in fire behaviour simulations in a Sierra Nevada mixed-conifer forest.

<u>Weather</u>	<u>FARSITE Model Parameters</u>
Temperature: 32°C	Timestep: 30 minutes
Relative humidity: 30%	Perimeter Resolution: 30m
Wind: 35 kmph (SE)	Distance Resolution: 30m
<u>Topography</u>	<u>FARSITE Fire Behaviour Options</u>
Slope: 15-30%	Crown Fire: enabled
Aligned with wind	Spot Fire Growth: enabled
<u>Fuel moisture (initial)</u>	Ignition Frequency: 1%
Live: 90%	
Dead: 4%	

TABLE 3. Societal benefits calculated in a Sierra Nevada mixed-conifer forest in an untreated landscape, after removing all understorey trees <15 cm, and after thinning from below to 50% of the initial stand basal area.

<u>Simulation</u>	<u>Stormwater capacity (m³)</u>	<u>Air pollution removal (t)</u>	<u>C sequestered (t)</u>
Untreated	219,768	179	1,294
Understorey Removal	193,468	179	1,294
Thinned to 50% BA	170,754	179	1,294

consider differences in forest structure. Instead, the software classified all forested stands as “Trees” with choices only for the types of ground cover, which did not affect any benefit of interest other than stormwater storage capacity. Dicus & Zimmerman (2007) found that CITYgreen also calculated zero benefits for all non-tree types of vegetative cover, thereby limiting its reliability in sites where forests were not the dominant vegetation on the landscape. Thus, as with all models, users should understand the assumptions and limitations when using this software. New software has been recently developed or modified, which may address some of the challenges experienced in the present and past studies. For example, the Street Tree Management & Analysis Tool (STRATUM) sums the benefits derived from individual trees, but may not be particularly suited for wildland settings (Dicus, 2006). The Urban Forest Effects (UFORE) model, which quantifies species composition, diameter distribution, tree density and other structural characteristics, seems especially promising, particularly because it is also able to calculate benefits derived from brush species (Nowak & Crane, 2000). While subtle, results here indicate that treatment-induced reductions in societal benefits can occur and therefore, fire managers must be cognizant of potential changes to not only fire hazard, but also societal benefits when implementing any fuel treatments

Largely because of the societal and environmental benefits that vegetation provides, proper fuels management is an essential but controversial component of any proper WUI management strategy. Because of the 2003 firestorms in southern California, which ultimately burned over 303,500 ha, destroyed 3710 homes, and killed 24 people, State legislation (California Senate Bill, 1369) now requires that private landowners modify vegetation within 30.48 m of any structure so as to reduce potential fire hazard. There is increasing concern that the increased clearance regulations will further degrade and fragment native vegetation, which has been significantly impacted by burgeoning urban sprawl and development (American Forests, 2003). It is imperative, therefore, for the prudent fire manager to consider both fire hazard and societal benefits when implementing any fuel modification treatment.

There are many fuel treatments available to fire managers, each with positive and negative aspects. WUI fire managers should not take a one-size-fits-all

approach to fuel modification, but should consider both the biophysical and sociopolitical factors present in a given area. Treatments currently available to land managers in California include prescribed fire, mechanical mastication, hand piling and burning, chipping, goats and other livestock, herbicides, and others. Prescribed burning is the most opposed tool in the WUI due to the potential for escape and lowered air quality. Even where socially accepted, it is often impossible to use prescribed fire on many sites until some other type of mechanical treatment has been conducted because of dangerously high fuel loadings. While prescribed fire is by far the most cost- and objective-effective means of reducing fuels, it will likely decrease in use in California as the population continues to expand.

Of note, one trait that facilitates the assessment of non fire-related aspects of vegetation is that many fire managers in the United States were educated in forestry or other resource management disciplines. This allows them to see beyond how various treatments will affect fire behaviour and better comprehend the multifaceted effects of vegetation manipulation. Unfortunately, it appears that wildland fire agencies are becoming increasingly more engrossed in emergency services and less in resource management. General consensus is that the fire suppression and resource management aspects in both the federal United States Forest Service and the state California Department of Forestry and Fire Protection are increasingly diverging into their own distinct entities, which will adversely affect the abilities of future fire managers to fully appreciate the non-fire aspects of vegetation management.

Fuel modification, however, is only one aspect of sustainable WUI management. In general, fire managers should also address four additional aspects of WUI management so as to reduce the costs and losses associated with wildfires. These other critical elements include construction standards, sound land-use planning, effective community education, and increasing fire suppression success. While priorities should be established dependant on the local situation, no element should be entirely absent in the management of WUI communities.

Construction standards and sound land-use planning will significantly impact the degree of fuel modification needed in a given area. Individual homes should adhere to adequate, enforceable regulations that

address fire protection in siding, vents, windows, and especially roofs, which are particularly susceptible to ignition from burning embers (Cohen, 2000).

Proper land-use planning that provides for appropriate housing density, home placement, and infrastructure needs, such as ingress/egress and water supply, is also essential (Schwab & Meck, 2005). New development in California must undergo intensive review by local government entities before building permits are issued. If sound land-use principles are not applied in the permit approval phase, then there will be a multiplier effect that will negatively impact the development for many years.

Obviously, older developments that were constructed largely before construction and land-use standards were enacted are usually at much greater risk to wildfire than newer communities where the right to develop was hinged on the ability to adequately address fire concerns. To reduce fire risk in California, even government-issued permits to remodel one's home can trigger mandatory upgrades to fire-resistant construction. For older developments, it is imperative to have adequate codes in place before a fire event and after the event subsequently disallow any new construction that does not meet new construction standards. While many victims of wildland fire have vehemently complained of burdensome government obstruction in rebuilding efforts, improved construction standards will reduce a cycle of repetitive loss. That said, it should be noted that higher construction standards will translate into higher construction costs. Given the high cost of housing in California, where the median home price for the State currently exceeds \$535,000 (U.S.), the need for affordable housing and fire standards will inevitably clash.

Effective community education is another critical component of effective fire management in the WUI. Education efforts must be developed for a specific target community based on the level of local knowledge. Managers in the WUI need not assume that community members are totally ignorant of the threat of wildland fire. Some communities are well aware of the threat, but lack specific knowledge on how to reduce their risk. Thus, funds allocated to public service announcements over mass media outlets such as radio may be essentially wasted in those communities. Further, research has shown that while cost-effective and requiring less effort, mass media advertising has little value in effecting change in the

behaviour of WUI residents (McCaffrey, 2004).

Instead, personal contact has the greatest impact on changed behaviour. However, it is virtually impossible for fire personnel to visit each home in its responsibility area given budgetary and time constraints. However, by organising interactive, informational displays where the public would likely be present, such as at a hardware store or county fair, fire personnel have successfully been able to provide personal contact with community members.

The final component of a proper fire management strategy is properly equipped and staffed fire suppression forces. Having the proper types and numbers of suppression equipment and personnel are essential to adequate fire protection in the WUI. For initial attack success, it is critical that the appropriate resources are in the right place at the right time. In general, a community decides their level of service, which is a measure of the percentage of fires controlled by initial attack, through voter-approved property taxes. It is the responsibility of fire administrators to allocate funds to specific resources within the organisation to best increase success of initial attack. If budgets are managed efficiently and the level of service is unacceptable for a given community, those residents must be willing to increase taxes on their property. However, in many areas it is extremely difficult to convince voters to increase property taxes, which subsequently limits the ability for fire agencies to properly respond to fire events.

Regularly, it seems that the fire suppression aspect of WUI management is overemphasised in the United States by both fire agencies and the public it serves. By first adequately addressing the other four elements of sound WUI management, the demands on the fire suppression community will be lessened and their effectiveness will subsequently be increased. Analogous to the military, when battling a formidable foe it may be more prudent and effective to first shape the battlefield than to simply add more soldiers.

In conclusion, countless anecdotal evidence and case studies suggest that the single most critical element for successful fire management in the WUI is collaboration with stakeholders from a diversity of worldviews (e.g., Dicus & Scott, 2006). Too often, fire managers in the U.S. have attempted projects only to fail due to unforeseen objections and resistance. Most commonly, fire managers believe that if only they could "educate" the public, the public would

willingly follow the direction of the fire manager. However, this attitude will generate fierce resistance and potentially doom a management proposal because it does not incorporate the worldviews and values of others who see the land from completely different perspective.

One of the most successful applications of a collaborative strategy in California has been the formation of local community FireSafe Councils, which purposefully seeks to include diverse interest groups from fields such as fire personnel, wildlife biologists, ranchers, developers, the insurance industry, the environmental community, builders, air pollution regulators, and others. While normally at odds with one another, these groups, through open dialog, consistently develop creative solutions that reduce wildland fire losses in the community while maximising other community values. To aid them, FireSafe Councils can apply for federal and state grants to fund educational products, fuels projects, pre-fire planning documents, and others. Whereas outside of this organisation many of the members have regularly been at odds with one another, FireSafe Councils allow them to see their collaborative ideas turned into action.

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