Drought, Fire and Fuel Treatment in Western US

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Abstract

The severity of recent fire seasons in the US has provided dramatic evidence for the increasing complexity of wildfire problems. A wide variety of indicators seem to point out worsening problems: area burned, funds expended, homes destroyed or evacuated, ecosystems at risk, and human fatalities/injuries all seem to be on the increase or have peaked in recent years. Recent national initiatives have stimulated heightened interest in fuel treatments. Fuel treatments are proposed widely to mitigate wildfire damages, though extant evidence for treatment effectiveness is largely anecdotal, relying on isolated observations or nonsystematic comparisons. Results from recent wildfires systematically studied in terms of treated vs. untreated comparisons suggest promising possibilities, although generalities must be made with caution. The concept of treatment effectiveness needs to be reconsidered when ignitions occur under prolonged drought conditions.

Recent fire seasons in the western US have pointed out the futility of attempting to exclude fire from wildland ecosystems. For example, burned areas in 2000 and 2002 exceeded the 10 year average, destroyed or damaged an average 800 buildings, and cost more than USD $1 billion in federal suppression expenditures (National Interagency Fire Center, 2003). As a consequence of program review and policy evaluations following both these years (i.e., National Fire Plan and Healthy Forests Initiative), increased emphasis has been placed on the need for pre-fire fuel treatments. Further impetus for the need to accelerate fuel treatments has been provided by studies such as USDA Forest Service (2000), Schmidt and others (2000), and US Government Accounting Office (1999), in which the condition of the nation's forests has been assessed regarding the effects of fire exclusionary policies during the 20th century. These assessments have suggested the need for hazardous fuel reduction using treatments such as prescribed fire and mechanical thinning so as to sustain forest health and restore ecosystem conditions, primarily in dry forests of the western US. Otherwise, the prognosis is that future fire seasons will continue to result in massive costs and destruction, such as witnessed in 2000 and 2002.

The purpose of this paper is to summarize lessons learned from recent fire seasons in the US, in which wildfires were fueled by prolonged drought, and to describe how these lessons inform ongoing research about fuel treatment effectiveness. In the aftermath of years such as 2000 and 2002, we tend to forget that periodic dryness is an ever-present reality of some forest environments, and that forests have adapted to drought and recurrent fires over the millennia. But humans by nature like to ponder questions regarding the root causes of the severe wildfire seasons, so we find ourselves pondering whether the massive fires were the result of drought, or worsening fuel conditions, or some other causal influence? In reality we wonder if such questions can be answered simply, for natural systems are usually much more complex and variable than we think.

Drought Definition And Metrics

Weather conditions that increase the threat of forest fires are well known, such as low precipitation and humidity, coupled with high temperatures and solar radiation, and high winds. However, the specific importance of each meteorological factor is not known for the climatic periods preceding historic large fires. Drought, which results from a combination of meteorological factors, is especially problematic (Haines and Sando 1969). Unfortunately the exact role of drought is unknown, probably because the term is used so informally and vaguely.

Unlike discrete events like wildfire, a drought sneaks up quietly, often under the guise of lovely, sunny weather. Meteorologists define drought as simply a shortage of water, usually associated with a deficiency of rainfall in an area, often unpredictable and unanticipated until we are in its midst. We are never sure when a drought begins until it is well under way and we are often unsure when it ends (McKee and others 2000). Often in the wildfire community we are only made aware of the magnitude of an ongoing drought by looking backwards and examining records for evidence of the lack of moisture or precipitation.

Another problem with describing drought is that there are few universal standards for describing and measuring the phenomenon—this may sound surprising when you consider how great of an impact we seem to attribute to droughts and wildfire occurrence/growth. However, wildfires provide only one among several contexts for speaking about droughts. Other contexts are provided by agricultural, meteorological, hydrological, or socioeconomic concerns. Further, spatial location is important in defining drought causes and impacts. For example, in any given year the 37 cm of average precipitation in northern Colorado may seem bounteous to neighbors in Nevada and Arizona, just as Sydneysiders might view Alice Springs as being under perpetual drought. So the concept of drought depends on who is affected, the depth of consequences, location, and other descriptors.

Predicting drought is somewhat like guessing about financial markets. Both drought and market runs (to the upside and down) are inevitable, yet no one knows when either process begins nor how it will unfold or how long it will last. Like a bull or bear market, both of which we know will occur in the future, we can be certain that society will need to contend with some form of drought in the future, but we really can’t say much more with any certainty.

Amid this confusion in describing drought, especially its impacts from a wildfire standpoint, numerous measurements have nonetheless been developed to assess the effects of prolonged drying trends on fuels and fire behavior. Some of the more prominent measurements of relevance from a fire standpoint include:

The Palmer Drought Severity Index (Palmer 1968) is a complicated soil moisture calculation used in the agricultural community to gauge the need for federal drought assistance. It measures the departure of the moisture supply at specific locations from standardized conditions. It has been reconstructed in fire history studies to link fire occurrence with drought periods, including links with El Niño and La Niña cycles.

The Keetch-Byram Index, developed by Keetch and Byram (1968), assesses fire potential based on the net effect of evapotranspiration and precipitation deficit in deep duff and upper soil layers on a scale from 1-800 (USDA Forest Service 2002). It was developed for use in the southern US but is now mapped nationally in the US.

The National Fire Danger Rating System (Deeming and others 1977) perhaps provides the most well-known drought measures from a fire standpoint, based on ambient and recent trends in coarse-scale environmental conditions (fuel, weather, topography). For example, the 1000-hr timelag fuel moisture content (TLFMC) and the Energy Release Component have been linked to the occurrence of late season fires outbreaks in the northern Rocky Mountains.

More recently, vegetation greenness maps are derived weekly from Normalized Difference Vegetation Index (NDVI) calculations based on AVHRR satellite observations. Maps include greenness relative to a reference standard, greenness relative to historic ranges for a specific pixel, and departures from average greenness for a particular point in time (Burgan and Hartford 1993).

The Standardized Precipitation Index (SPI) was developed in Colorado based on current and historical precipitation data for a particular location (McKee and others 2000). SPI is based on precipitation deviation from the average surplus or deficit for a specific location, and technically can be used to identify the start and end of drought episodes, if a long enough record is available.

The above list is not intended to be all-inclusive and could be expanded, but we assert that there is no standard measure of drought that is universally accepted and used by the fire management community—and perhaps there shouldn't be: No single indicator works best for all regions and intended applications, so why search for one universal index?

Wildfires And Drought

Unlike a wildfire, drought isn't viewed as a discrete event with a clear beginning and end. Yet drought serves as a precursor to wildfire and other natural disturbances, such as insect attacks on weakened trees. In fact, some may view wildfire simply as one among several manifestations of prolonged drought. Even so, drought is sometimes overlooked or underemphasized in terms of causation of wildfires events, perhaps because of perceptual, definition, and/or measurement problems noted above. For example, the recent emphasis on fuels abatement in the US apparently underplays consideration of drought in worsening the impacts of recent fire seasons. Perhaps this oversight follows from the difficulty of isolating the relative contributions of fuels vs. drought (or their interactions)--at least no one seems able to quantify which is more influential in pushing fire seasons to the extremes, such as those observed in 2000 and 2002.

What seems clear is that drought does make more fuels available for combustion and seems to push fire behavior beyond thresholds of firefighter control efforts. Drought effects also seem to vary by elevational temperature/moisture gradients. Thus high elevation, moist-cold ecosystems burn more readily during prolonged droughts, as compared to non-drought years. These systems support plenty of biomass, but may not dry sufficiently to burn except during the drought years. These forests burn with characteristic high severity, stand-replacement fires following a prolonged drought. At these times, firefighters can do little more than attempt indirect attack, work the cooler sectors (e.g., flanks and areas of origin), and mostly wait for a weather change.

The same principles seem to apply during drought years in lower elevation, warm-dry forests as well, but for different reasons. Historically, these ecosystems burned more frequently than the high elevation forests, but decades of fire exclusion have also led to higher surface fuel loads, higher density of smaller diameter trees and understory shrubs that provide ladders into the tree crowns, and created a more continuous fuelbed across the landscape—all contributing to greater likelihood of crown fires. So during drought years, these forests also burn uncontrollably.

Certainly the fires that burned in Colorado during the ongoing 2002 drought seemed to follow this trend of uncontrollable fires at both high and low elevations. Thus upper elevation Engelmann spruce-subalpine fir (*Picea engelmannii-Abies lasciocarpa*) and lower elevation ponderosa pine-Douglas-fir (*Pinus ponderosa-Psuedotsuga menziesii*) forests burned with high severity during 2002. The higher fuel loads and structural changes (i.e., increased density of small trees, lower crown bases) in the lower elevation forests resulting from the decades of fire exclusion may provide a major distinction between the severe burning observed at both elevations during 2002 in Colorado.

Fuel Treatments

Fuels management consists of activities undertaken prior to the onset of a fire to ameliorate subsequent fire effects so as to achieve ecosystem management objectives. Typically, these activities consist of fuel treatments in a stand or group of stands, management practices, and fuelbreaks. Fuel treatment activities include disposal or redistribution on site (e.g., prescribed burning), mechanical thinning, physical removal, type conversion, or isolation (Omi 1997). Management practices in which fuels are managed include livestock grazing, timber management, water/soil stabilization, preservation, and management for ecosystem sustainability. A fuelbreak is a strategically located, wide block or strip on which a cover of dense, heavy, or flammable vegetation has been permanently changed to one of lower fuel volume and reduced flammability (Green 1977, Agee and others 2000).

In this portion of our paper we summarize our analysis of the severity of wildfires that burn through areas subjected to fuel treatments, primarily pre-commercial (i.e., small diameter) thinnings, with or without subsequent application of prescribed fire, as compared to untreated control plots. However we also wish to describe the performance of similar treatments under drought conditions in 2002, and conjecture about reasonable expectations for the future.

Fuel treatment traditionally has focused on wildfire hazard reduction, either by physically rearranging or removing flammable biomass from the fuels complex. More recently emphasis has broadened to encompass fuel manipulations, again primarily rearrangement or removal, required to allow ecological restoration of fire. Earlier fuel treatments were carried out as part of fuelbreak construction and maintenance activities. Until recently, most evidence for fuel treatment effectiveness (or ineffectiveness) was anecdotal, stemming for the most part from isolated observations by observers in the field that a crownfire might drop to the surface or exhibit less behavior upon encountering a fuelbreak or treated area. Until recently, most studies lacked quantifiable documentation or did not provide systematic comparisons between treated versus untreated areas, with accompanying statistical rigor, including replications.

By contrast, starting in 1994 our studies have focused on systematic measurement of differences in the severity of wildfires that burn through areas subjected to fuel treatments, primarily pre-commercial or "waste" (i.e., small diameter) thinnings, in some cases with subsequent application of prescribed fire, as compared to untreated control plots of similar aspect and elevation. All of the areas in our studies were burned by wildfires that spread from untreated areas (i.e., no management activities in the last 20 years) into stands that were treated to reduce fuel hazards recently (i.e., less than 10 years prior to wildfire outbreak). In addition, study sites were selected where no suppression activities or fuelbreaks would compromise treated-untreated comparison.

Our studies include eight wildfires that burned through stands where fuels had been treated previously, including fires in Colorado, California (2), Montana, Arizona, New Mexico, and Mississippi (Table 1). A ninth wildfire, the 2002 Hayman fire in Colorado is currently under study. Specifics of our methods and results are noted in Omi and Martinson (2002) and Pollet and Omi (2002), so will not be discussed here in favor of a more general summary. Table 1 shows some variability in the evidentiary strength of differences between crown scorch, stand damage, and ground char provided by the fires studied, but the overall trend is that wildfires burn less severely in stands where fuels have been treated as compared to adjacent untreated controls.

Table 1. Summary of differences in crown scorch, stand damage, and ground char in untreated vs. treated stands in eight wildfires occurring during 1994-2000 (From Omi and Martinson, in prep.).

Fire name, location, and date	Crown Scorch	Stand Damage	Ground Char
Hi Meadow, CO 2000		x	
Megram, CA 1999	x	x	x
Webb, MT 1994	x	x	
Cerro Grande, NM 2000	x	x	x
Tyee, WA 1994	x	x	x
Cottonwood, CA 1994	x	x	n/a
Hochderffer, AZ 1996	x	x	n/a
Fontainebleau, MS 1999	x	x	x

x indicates significant reductions in treatment vs. control ($p = 0.1$);
n/a not available

The reasons for the general reduction in wildfire severity noted in Table 1 are mostly related to forest structural differences in treated vs. untreated areas. In the treated areas, surface and ladder fuels have been reduced, tree densities are lower, and crown cover is lessened. Consequently, fire severity is lowered in treated areas as might be expected in areas where crown fire potential is reduced (Agee 1996). Further analyses have revealed that residual tree diameters and historic fire regimes appear to be particularly important to distinguishing stand damage in untreated vs. treated stands. Thus the most effective treatments will likely be those that complement ecological restoration objectives. Our findings should be broadly applicable to long-needle pine and drier mixed conifer types (Martinson and Omi in prep.).

Our results were based on retrospective studies, where agencies had conducted pre-fire fuel treatments and we had no control over the stocking densities or treatment specifications. By contrast, the fire and fire surrogate studies (McIver and others 2001) should provide additional insight in a more tightly controlled experimental environment. But inferences from fuel treatment projects applied at the stand level may not extend to landscape scale fire disturbances. Similarly, fuelbreak effectiveness is controversial and has not been established at the landscape scale, except in simulation studies (e.g., Finney 2003).

Nonetheless, fuelbreaks provide options for managing wildfires, anchor points for prescribed fires, and safer access/egress for firefighters to make a stand against the oncoming fire or to take advantage of airtanker retardant drops (Agee and others 2000). Otherwise, in the absence of firefighters we have observed that fires sometimes spread through the treated area, albeit with reduced fire severity, before resuming high severity burning patterns in untreated areas. In sum, suffice to say that many different burning patterns emerge from wildfires that spread into areas where fuels have been modified.

Fuel Treatments And Drought during the 2002 Fire Season

Generalizations about drought impacts on fuel treatments are as elusive as quantifying relationships between drought and wildfires, as might be expected. Intuitively, we would expect droughts to make stands more flammable and landscapes more susceptible to widespread burning, so we would also expect fuel treatments to be less effective if ignitions occur following a prolonged drying period. However, exceptions occur depending upon circumstances, e.g., time of day and weather conditions accompanying the wildfire encounter with the treated area.

The 2002 fire season provided several examples of the performance of fuel treatments under drought conditions. In particular, here we summarize evidence from several case-study fires, with greatest focus on the Hayman fire in Colorado, which was the subject of intensive review (Graham 2003), and is currently undergoing more detailed investigation as part of a Joint Fire Sciences research project (Omi and others 2000). Other incidents (e.g., the Rodeo-Chediski and Cone fires in southern Arizona and northern California, respectively) also included areas with fuel treatments in place prior to fire outbreaks and will be discussed in slightly less detail, based on information from other factual sources.

In the 54,000 ha Hayman fire, an unprecedented high severity crown fire run (27,000 ha in one day) burned during over several pre-existing fuel treatment areas that apparently made little difference in terms of slowing the fire spread or reducing fire severity, especially during the major fire runs during June 8-10. Based on analyses of the PDSI, 1000-hr TLFMC, NDVI (indexes mentioned above), Finney and others (2003) conclude that the fuel moisture conditions in the spring of 2002 in central Colorado were among the driest seen in at least 30 years and perhaps much longer. Further, they add that unlike other years where near-normal spring conditions gave way to short-term drying and largely wind-driven fires of short duration, the fuel moisture conditions for the Hayman Fire were set up in April and May. Later, under less extreme burning conditions and another set of fire runs observed during June 11-18, the Hayman fire spread was slowed or burned with lower severity when fuel treatment areas when fuel modification areas were encountered (Finney and others 2003).

Even under the severe drought conditions preceding the 184,000 ha Rodeo-Chediski fire in southern Arizona, reduced burn severities were noted in fuel treatment areas. Treated areas supported reduced crown densities, elevated canopy heights, and diminished surface fuel loadings as compared to untreated areas. Although some treated areas did burn with high severity, all but one treatment type showed significantly less proportion of total area in the high severity class as compared to the untreated areas. The exception occurred in pre-commercial treatment areas where fuels had been lopped and scattered (Apache-Sitgreaves

National Forests 2002), i.e., residual stems and branches were cut into short sections and scattered over the forest floor.

The 800 ha Cone Fire burned into the Blacks Mountain Experimental Forest in northern California under severe fire behavior conditions of wind, low humidity, and low fuel moisture. Stands that had received thinning of ladder fuels followed by prescribed fire burned with low severity, while thinned stands without the follow-up prescribed fire treatment had sufficient surface fuels to severely scorch trees. Untreated stands burned with highest severity, total tree kill, forest floor consumption, and canopy consumption (Nakamura 2003).

These few examples suggest that we should reasonably expect mixed results when fuel treatment areas burn under drought conditions. In some areas, the treatments might be expected to slow the fire or reduce the number of fire-killed trees; however, other treated stands may burn and sometimes may not slow a fire's spread or burn with low severity. In essence, fuel treatments cannot be expected to provide blanket insurance against damaging fire runs across a landscape, especially in the presence of high winds and low moisture or if residual fuels are left on-site following treatment.

Discussion and Conclusions

Drought conditions may obscure or confound the changes in fire behavior due to the fuel treatment, but we need to remember that fuel treatments are not intended to stop wildfires in and of themselves. During most fire seasons, fires severity may be reduced when, for example, a crown fire drops to the surface once it encounters an area where surface and ladder fuels have been reduced. This effect may be obscured when a wildfire encounters a treated area during a drought, especially if residual surface fuels persist after treatment (or sufficient time has elapsed since initial treatment). Also, the increased solar insolation from the opening of an overstory canopy will result in higher biomass of fine fuels (i.e., grasses) that can increase spread rates through fuel treatment areas.

Fuel treatment performance during droughts will likely be mixed, depending on fire intensity and weather, treatment design criteria, time elapsed since last entry, placement of treated areas across a landscape, and other criteria. Fuel treatments will always involve a degree of uncertainty, unless of course we should ever achieve the idealized fully regulated forest, where all areas and ecosystems in need of treatment have been identified, prioritized, treated, and maintained. The likelihood of achieving this target anytime soon is quite low because of the large backlog of areas in need of treatment and ecosystems in need of restoration. So we will likely live with these uncertainties for the foreseeable future. In the face of such uncertainties, decision makers should adopt an adaptive management perspective and be permitted to learn from experiments (and mistakes).

The biggest challenge facing land managers will be the creation and maintenance of sustainable (fire-safe) forests, even in the face of inevitable droughts that will recur and contribute to large fires on the landscape. We need to acknowledge that fuels treatment may provide a measure of protection for some, but not necessarily all fire events.

Policy makers and publics need to realize that fuel treatments should always be viewed as works in progress in a changing environment. Once installed, a treated area will require maintenance, especially surface and ladder fuels that may persist following initial treatment or that accrete in the interim. Also, a constantly changing environment, including drought and warming episodes, will likely create moving targets in terms of fuel treatment performance evaluations. Other changes might result from the pattern of future wildfires, human population demographics, and insect/pest outbreaks. Similar disturbances might influence decisions about desired species- and age-distributions, optimal tree densities, and needs for tree removal and/or plantings in treated areas.

One of the biggest keys to long-term success in fuels management is the education of key publics, including common people affected by wildfires and fuel treatments, but also land managers and policy-makers. Especially promising activities include collaborative learning processes where participants understand the state of science and develop reasonable expectations for future outcomes.

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