Evaluating Vegetation Treatments for Change in Fire Behavior and Fire Effects

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Introduction

This report is a review of methods to evaluate how effectively vegetation treatments change fire behavior and fire effects in different vegetative communities across New Mexico. To monitor the effectiveness of vegetation treatments, the land manager must consider the goals and objectives of each specific vegetation treatment project. To best track the long-term success of vegetation treatments, one needs to focus on the most efficient monitoring variables, including those variables that can be manipulated by land management actions within our control. Over the long term, monitoring these standardized variables can help us learn more about forest ecosystem health and determine whether vegetation treatments are achieving desired results in fire behavior and fire effects. By concentrating on variables within our control, and using monitoring data to help implement adaptive strategies, it is possible to modify management practices to achieve desired goals and objectives.

When this document refers to vegetation treatments, it almost always means removal of woody plants that have encroached or in-filled because of fire exclusion over the past century. A treated forest stand will be less likely to be completely consumed when a fire eventually burns through it. The best protocols restore historic structure to the stand, emulating what we think conditions were before fire was excluded from the forest ecosystem. Other protocols can focus more on reducing fuel loads to reduce the risk of catastrophic fire, without the emphasis on full ecological function in restoration protocols. If the land manager’s emphasis is on reducing the threat of fire, either of these approaches reduces fire threat; however, restoration of full ecological function is always preferred, and can be accomplished at very little additional cost. As demonstrated by projects throughout the region, a combination of historical stand data and ecological restoration needs can be a solid basis for goals and objectives.

When we think about fire behavior and fire effects, we are interested in an appropriate duration, intensity and frequency of fire. Another way to say this is that we generally do not want a stand-replacing fire, yet neither do we want to exclude fire. Instead, we want frequent, low-severity fires, the historic fire regime for most of the plant communities in New Mexico. The treatment protocols usually applied to these plant communities can also be applied to plant communities with other fire regimes, with the same effect. In other words, fuels can be reduced in areas with a low frequency, high severity fire regime, to the point that a fire can be run through the stand at less-than stand replacement severity. This would not be restoration but might be proper management if the goal is, for instance, to protect water sources.

Riparian areas are a special case. They are an example of a system where fire was not the historic disturbance factor, but over-bank flooding was. Under current conditions, especially along larger rivers away from mountain ranges, dense salt cedar and Russian olive burn with stand-replacing severity, making fire an important factor to consider in management actions.

This report begins with a review of the science supporting what vegetation characteristics to monitor when considering fire effects. Next is a section on the importance of slash reduction, then section on riparian areas and fire. The 2008 Flagstaff workshop and recommendations of what to monitor are then summarized.

In the long term, the monitored variables will need to be run through fire models to help feed decision making processes. Target goals can be associated with what stand characteristics were determined to be historically, or based on considerations like fire risk reduction or habitat improvement.

Vegetative Treatments

Prescribed fire and mechanical fuel treatments are increasingly used by managers to change the only factors in the fire behavior formula they can, the quantity and continuity of fuel (Stephens and others 2012); thus, we need to measure what we can manage. Before it was excluded from the ecosystem, fire acted as a natural restorative agent by reducing litter, removing unhealthy trees, snags, and woody debris, thinning small trees, and creating diversity in landscapes at a spectrum of scales (Hunter and others 2007.) So, one approach to a methodology for evaluation would be to monitor for those things that the fire removed and/or affected – litter, coarse woody debris, and ladder fuels.

Research has consistently shown that the risk of crown fire can be lowered if fuel loads are reduced, small-diameter trees are removed, and ladder fuels are minimized. The relevant reductions are measured by basal area, overall tree density, and density of small-diameter trees (Lowe 2006). For yellow pine and mixed conifer forests, the evidence seems overwhelming: with few exceptions, fuel treatments that incorporate explicit removal of surface fuels can be expected to significantly reduce fire severity and canopy tree mortality, even under relatively extreme weather conditions. Measures of fire severity – char height, and height and percent of crown torch and scorch – are significantly reduced in treated forest compared to untreated forest at most sites (Safford and others 2012).

Although fuel treatments are a means to limit the size and intensity of wildfires, few experiments are available to analyze the effectiveness of treatments. In a combination of actual measures and modeling, prescribed burning significantly reduced the total combined fuel load of litter, duff, 1, 10, 100, and 1000 h fuels by as much as 90%. This reduction significantly altered modeled fire behavior in both mechanical-plus-fire and fire-only treatments in terms of fireline intensity and predicted mortality (Stephens and Moghaddas 2005b).

The Fire and Fire Surrogate Study (Schwilk and others 2009, Stephens and others 2009) provides insight into the measurable variables that matter most to fire effects. That study models fire behavior and effects by using actual on-the-ground measurements. Schwilk and others (2009) looked at 12 variables representing the overstory (basal area and live tree, sapling, and snag density), the understory (seedling density, shrub cover, and native and alien herbaceous species richness), and the most relevant fuel parameters for wildfire damage (height to live crown, total fuel bed mass, forest floor mass, and woody fuel mass). The variables measured were: trees ≥4 in dbh (diameter breast height) and saplings >4 ft tall recorded to species, status (alive, standing dead, dead and down), dbh, total height, and height to the base of live crown. Cover was estimated for grasses, forbs, and shrubs. Mass of litter, duff, and woody surface fuels were estimated using either Brown’s planar intercept method or a destructive sampling method. For the 1000-hour fuel size category, the diameter and decay class (sound or rotten) of each log were recorded. Stephens and others (2009) adds that quantitatively evaluating the source of fire hazard from surface, ladder, and crown fuels, or their combination, can help managers design more effective fuel treatments.

In modeling examples, Ager and others (2010) used FVS to simulate fire behavior in the WUI of Eastern Oregon. Inputs were canopy bulk density (kg/m^3), height to live crown (ft), total stand height (ft), canopy cover (%), and fuel model. In another study, Evans and others (2015) used the LANDFIRE data layers - elevation, slope, aspect, canopy closure, fuel model, canopy base height, and canopy bulk density – to model the effect of fuel treatments on fire behavior for 12 different CWPPs. Another LANDFIRE assessment of fuel treatment effectiveness used the robust and parsimonious data set of pre-fire canopy cover, fuels, and topography (Wimberly and others 2009). Mason and others (2007) measured surface and canopy fuels and used them to develop custom fuel models in NEXUS 2.0 to estimate torching and crowning indices.

More detailed measurements can help explain some differences in results. In a post-fire comparison of fire effects, among variables related to fire weather, fuel loading, and treatment age, ten-hour fuel moisture was a better predictor of tree survival in untreated stands than in treated stands, while fuel loading was a better predictor of survival in treated stands. These results are consistent with growing evidence that fuel treatments that include removal of surface and ladder fuels in frequent-fire forests are highly effective management tools for reducing fire severity and canopy tree mortality (Safford and others 2012).

In this same study, surface fuel loadings averaged 37.51 tons/ha in untreated stands and 15.47 tons/ha in treated stands. Fuel loading (1–1000 + h fuels) was significantly negatively related to survival in the treated stands, but not in untreated stands; undoubtedly, down woody debris loading was important in untreated stands, but its importance in survival was overshadowed by other factors. Where fuel loadings were available for both treated and untreated, the mean difference was 20.16 tons /ha (Safford and others 2012).

Species identity also has a significant effect on post-fire survival probability (Safford and others 2012). Many forests that today are dominated by dry mixed conifer species may not have historically been mixed conifer forests, but have been in-filled with fire-intolerant mixed conifer species (e.g., white fir) following fire exclusion or were altered by harvesting of selected species (e.g., ponderosa pine). Increases in stand density and corresponding changes in structure and species composition have altered potential fire behavior on many warm/dry mixed conifer sites, shifting fire potential from low-severity surface fire toward high-severity crown fire (Margolis and others 2013).

Slash Reduction

Both an extensive literature review and case study results support a manager consensus that forest thinning followed by some form of slash removal is most effective for reducing subsequent wildfire activity (Hudak and others 2011). Safford and others (2012) found surface fuels are often high after the first treatment entry, and if they are not reduced by some means, they can burn in a subsequent wildfire and contribute to increased fire severity effects (e.g., greater tree mortality). In addition, mastication does not remove fuels from the site, and although flame lengths and spread rates may be reduced (and fire control efforts aided), modeling and empirical evidence show that tree mortality can be very high in burning masticated fuels.

Johnson and others (2011) showed this need to reduce slash in an extensive modeling study. They used the Fire and Fuels Extension to the Forest Vegetation Simulator (FFE-FVS) to simulate fuel treatment effects on 45,162 stands in low- to mid-elevation dry forests (e.g., ponderosa pine and Douglas-fir of the western United States. They evaluated treatment effects on predicted post-treatment fire behavior (fire type) and fire hazard (torching index). FFE-FVS predicted that thinning and surface fuel treatments reduced crown fire behavior relative to no treatment; a large proportion of stands were predicted to transition from active crown fire pre-treatment to surface fire post-treatment. Intense thinning treatments (125 and 250 residual trees/ha) were predicted to be more effective than light thinning treatments (500 and 750 residual trees/ha). Prescribed fire was predicted to be the most effective surface fuel treatment, whereas FFE-FVS predicted no difference between no surface fuel treatment and extraction of fuels. This inability to discriminate the effects of certain fuel treatments illuminates the consequence of a documented limitation in how FFE-FVS incorporates fuel models (Johnson and others 2011).

Despite the universal recommendation to remove, or at least reduce, activity fuels, researchers are undecided whether thresholds could be easily established to inform relevant action (Egan 2009). Treated areas are never entirely fireproof and do not always serve as fire barriers (Lowe 2006). One significant concern is that characteristic features of extreme fire behavior depend on conditions undetectable on the ground, namely invisible properties such as wind shear or atmospheric stability (Werth and others 2016).

Riparian Systems and the Role of Fire

Changes in human populations, water use, climate, and related disturbances are impacting riparian ecosystems throughout the western United States. Nowhere is this more pronounced than in the arid American Southwest (Gutzler 2013, Molles and others 1998, Webb and others 2007). Changes in southwestern riparian ecosystems can include loss in riparian vegetation, fire, urbanization, and channelization of stream courses. To manage these changes and improve ecosystem resiliency for the future, a better understanding of the impacts of stressors and disturbances on southwestern riparian ecosystems, and especially on resources of high value from human and ecological perspectives, is needed (Johnson and others 2018).

The research literature contains limited information on fire behavior in riparian areas, especially specific to the Southwest. Riparian communities are neglected in fire work possibly because the major historic disturbance wasn’t fire, but over-bank flooding. The same principles of reducing fuel loads, raising crown base height, and decreasing canopy bulk density would apply in riparian forests, but the threshold values are even further from being established than they are in upland pine and mixed conifer vegetative communities. An additional confounding factor is the need to separate narrow headwater riparian areas from the “bosque” gallery forest along broad, lowland rivers when discussing the historic range of variability and appropriate treatment.

Research on Fire Effects in Riparian Ecosystems

The effects of wildfire on riparian vegetation have received little research attention relative to effects of flood and drought (Johnson and others 2018). Most studies of fire in arid land riparian systems have focused on cottonwoods and saltcedar, largely due to concerns that wildfire will facilitate replacement of the former by the latter (Busch and Smith 1995, Drus 2013).

Despite the focus of ongoing research on the effects of fuel treatments, results from studies specifically conducted in riparian areas are limited. Fire is increasingly recognized as historically common in many riparian areas. As in surrounding uplands, fire suppression has contributed to the accumulation of fuels in riparian areas. Yet, for most riparian plant communities, few data are available on fuel loads, fuel characteristics, or fuel distribution (Dwire and others 2016).

A recent, comprehensive review of riparian area fuel treatments is RMRS-GTR-352 by Dwire and others (2016). This publication reviews and synthesizes research on the effects of wildfire and fuels treatments in riparian areas of the interior western United States, including fire effects on riparian ecological function, mechanical treatments and prescribed fire effects on riparian resources, suggestions for monitoring, and case studies. They do not directly address fuel treatment effects on fire behavior, but some of their observations are worth noting here.

According to Dwire and others (2016), fire regimes in riparian areas relative to adjacent uplands vary depending on physical features of the watershed, location within a given watershed, vegetation type and fuel characteristics, and disturbance and land use history. In many forested riparian areas, fires are generally thought to occur less frequently than in adjacent upslope forests. Patterns observed for fire behavior, intensity, and severity in riparian areas are similar to those reported for fire frequency, i.e., highly variable. Fires in riparian areas can be less severe, as severe, or more severe than in adjacent uplands, depending on the local topography, vegetation characteristics (especially fuel moisture and loading), and fire weather.

Burn severity depends on fire intensity and the degree to which soils and vegetation are fire resistant. Fire severity can be greater in riparian areas if streamside fuel loads accumulate at greater rates relative to uplands (due to fire suppression, “hands-off” riparian management, or natural processes) and if pre-fire moisture levels are low (due to drought or season). High riparian fuel loads can influence fire spread by serving as “wicks,” especially where adjacent uplands have been harvested or actively managed for fuel reduction (Dwire and others 2016).

The condition and structure of live and dead fuels, topography, regional and local weather, and climate influence fire intensity and other components of fire behavior. Moisture content of various fuel strata can be a critical feature in determining how some riparian stands burn relative to uplands. Fuel characteristics include amounts of different size classes, extent of decay, horizontal and vertical continuity of the fuel bed, chemical content of the vegetation, and the fuel moisture of live and dead material. These fuel characteristics contribute to ignition probability, the ability of a fire to spread, and the intensity of the flaming fire front. Differences in fuel characteristics and distribution can influence how riparian areas burn relative to uplands (Dwire and others 2016).

Where vegetation and fuel profiles are similar across upland and riparian stands, they are likely to burn with similar frequency and intensity. Differences in riparian and upland vegetation result in differences in fuel profiles and total fuel loadings. Streamside areas frequently have more complex vertical layers within the canopy and subcanopy—that is, well-developed ladder fuels, more fine fuels, and greater fuel moisture than surrounding uplands—components that are strongly predictive of riparian fire severity (Dwire and others 2016).

Riparian fuel loads data are not available for most vegetation types, and the extent to which differences in forest structure and fuels between riparian areas and uplands affect fire behavior remains somewhat speculative. When estimates for fuels are required for project planning, resource specialists, particularly fuels specialists or fire management officers, frequently use fuels photo-series for the appropriate forest type and region. Managers compare field conditions with the photos to assess approximate fuel loads (Dwire and others 2016). FWRI has been compiling a fuel load photo series for NM riparian areas, but progress has been slow.

Determination of desired riparian conditions for fuel loading indicators remains challenging. Many riparian areas have been compromised by past land and water use. Restoration of natural conditions can be difficult, especially with limited understanding of historic or natural conditions. Lack of agreement among resource specialists on optimal canopy and understory species composition, stem densities, and other habitat components is not uncommon. Information on riparian fuel loads is also very limited, and estimates or targets for near-stream fuel profiles need to consider the inherent productivity of streamside areas, as well as departure from the natural fire and disturbance regime (Dwire and others 2016).

Riparian areas are part of the landscape. Leaving riparian areas untreated when fuel loads in surrounding uplands are planned for treatment should be done only after careful thought. Riparian fuel loads have been influenced by fire suppression and administrative protection policies and could be considered hazardous in some wildland environments, as well as the wildland-urban interface (Dwire and others 2016).

One conclusion reached in Dwire and others (2016) appears as a blanket statement, but it needs to be qualified. They conclude that in the southwestern United States, prescribed burning is not recommended in native riparian woodlands, apparently extrapolating from the observation that wildfires have destroyed native woody vegetation and fostered the spread of salt cedar. They also recommend that managers consider the role of streamside trees as potential sources of instream large wood; therefore, mechanical treatments that remove streamside conifers are not recommended, particularly in watersheds with histories of clear-cut logging or streamside tree removal. These recommendations are justifiable if the trees are large and fire-resistant.

Pre- and post-monitoring of riparian fuel reduction projects is critically needed. Each individual fuel reduction project is essentially an ongoing experiment; research cannot keep up with assessing the impacts of the wide range of fuel treatments that are being conducted in near-stream environments. For treatments that are conducted over several years and require multiple entries into project areas, longer-term monitoring of populations and riparian and aquatic habitat variables could assist in determining if certain treatment combinations or sequences are having beneficial, neutral, or adverse effects on species or habitat variables of interest. Follow-up monitoring for achievement of project objectives (short- and long-term) is critical to understanding the impacts and influence of fuel management, particularly in riparian areas (Dwire and others 2016).

Examinations of fire that take into account flow modifications, native and nonnative plant responses, and response of animal communities to changes in vegetation are needed. A recent report by Johnson and others (2018), published as RMRS-GTR-377, examined these factors. That report included a case study conducted along the Middle Rio Grande; that case study is excerpted in the following section. Note that the original report has technical references that are not included here.

Middle Rio Grande Case Study

> With several decades of research on hydrology, wildfire, plants, and animals, the Middle Rio Grande in central New Mexico is an ideal case study of changing disturbance regimes and their ecological effects. As the role of flooding has diminished along the

Middle Rio Grande, wildfire has grown from a minor component of the disturbance regime to an increasingly important influence on plants and animals.

Most fires that enter the bosque are accidentally ignited and burn with mixed intensity until they are contained by firefighting crews. The number of ignitions increases with proximity to larger towns and cities, but the size of fires increases with distance from these areas. Most fires occur in the dry spring and early summer period and the number of fires tends to be greater during years with low precipitation. Since the beginning of a long-term drought in 2000, at least 40 percent of this 1809-acre study area has burned and some portions have burned multiple times.

With the lack of high-magnitude flooding, the bosque has accumulated large quantities of litter and woody debris. Nonnative plant species, especially Russian olive and saltcedar, have spread as soil moisture declined, increasing the density of woody plants in the understory. These fuels, combined with the spatial arrangement of the forest, have contributed to increasing fire sizes and intensities that are likely outside the natural range of variability in the Middle Rio Grande.

Several studies have examined responses of native and nonnative woody vegetation to wildfire in the Middle Rio Grande. Results are varied, indicating that spatial and temporal factors interact with fire in shaping riparian forest composition. Several patterns, however, have emerged with the response of cottonwood and other woody plants. For instance, topkill vulnerability varies among taxa, size classes, and fire severity. All deciduous riparian tree taxa can recover from topkill by producing basal sprouts, epicormic sprouts, or root suckers. The success of vegetative recovery, however, is affected by numerous factors that vary among species and wildfire sites.

Cottonwoods are extremely vulnerable to topkill from bosque fires. Most, if not all, above-ground mortality occurs immediately after fire. In areas where fire severity is high enough to consume all organic matter on the forest floor, all cottonwoods and other woody species are top-killed. Topkill rates are lower for trees in areas burned with moderate severity (78 to 100 percent of trees killed) and light severity (52 to 70 percent of trees killed). (Table 1 in Johnson and others (2018) shows post-fire estimates results for both topkill and basal sprouting.)

Managed flooding and mechanical fuel reduction can increase resistance to topkill of cottonwood, but only to a limited extent given their high vulnerability to fire and the difficulty of removing all sources of fuel from the understory. Woody riparian plants recover vegetatively from wildfire through production of basal sprouts, root suckers, and (in the case of cottonwoods) epicormic sprouts. Their production and survival, however, vary among species and study sites.

Johnson and others (2018) observed epicormic sprouting of cottonwoods only at one site that burned with light to moderate severity. They also observed post-fire germination of cottonwoods at a site burned in March of 2008 and partially flooded in June of that year. They cite another study that observed saplings in post-wildfire sites along the Middle Rio Grande that were flooded within 2 years of being burned. They conclude that a combination of fire and low-magnitude flooding can act as a replacement for high-

> magnitude flooding along this heavily regulated stream, where over-bank flooding is concluded.
>
> Wildfire removes cottonwood canopy, creates snags and fallen debris, and induces resprouting of woody plants, especially saltcedar. Under the current disturbance regime, mortality of large riparian trees will continue to increase due to wildfire, drought, and senescence. Post-wildfire replacement of cottonwood by Russian olive and saltcedar will change the structure of the Middle Rio Grande riparian forest by increasing the density of low-stature vegetation and decreasing canopy height.
>
> Because riparian dynamics, including recovery from wildfire, are coupled with hydrology of regulated streams, we need hydrological projections that incorporate future water use and climate change scenarios. With this information, we can determine which species of plants will naturally sustain themselves and which will require adaptive management in an increasingly arid Southwest.

2008 Flagstaff Workshop Recommended Monitoring Indicators

On 15-16 October 2008, the Southwest Ecological Restoration Institutes (SWERI) hosted a workshop (Egan 2009) that has never received the attention due it. The participants built a common understanding of the types of monitoring that are occurring in forested ecosystems of the Southwest; selected an efficient, robust set of biophysical variables that can be used by land managers and scientists to monitor the effectiveness of restoration/land treatments; and developed strategies to overcome common challenges to effective forest monitoring and its integration into land management decision making. An invited group of individuals representing federal and state agencies, environmental non-profits, academic institutions, and consulting firms participated. Participants worked in specialty groups and plenary sessions.

Workshop attendees were asked to identify the most robust variables for monitoring the effectiveness of restoration treatments, and were divided into one of four working groups: Botany, Fire and Fuels, Trees and Forest Structure, and Wildlife. In the workshop, riparian systems were not part of the planned discussion, and do not appear to have been brought up in the break-away groups. This is omission not surprising; Hunter and others (2007), in an otherwise comprehensive review of fuels treatments in ponderosa pine landscapes, only mentioned riparian in the context of too many hillside trees using too much water and reducing its availability to riparian areas.

Each individual was provided with a list of biophysical variables prior to the workshop. Participants were asked to review the variable list and identify and discuss any missing variables. Participants then selected five variables they believed were essential to the monitoring of their chosen working group theme. Individual votes were tallied to identify the top five variables within each working group, and the groups ranked each of the identified variables against 15 different criteria composed of four different dimensions: scientific, implementation requirements, policy and adaptive management, and ecosystems.

Members of the Fire and Fuels Group identified eight variables as useful for fire and fuels evaluations. Several of these - surface fuels, tree characteristics, crown base height - were also identified as important by the Tree and Forest Structure Group. Their scorings and discussion are presented below. Note that most of this section is excerpted from the workshop report (Egan 2009); the full report is available from the ERI website.

Surface Fuels on a Planar Transect

(Score of 13 in Fire and Fuels)
Surface Fuels: Live and Dead (Score of 14 in Tree and Forest Structure)

This variable is essential, useful, and relatively easy to monitor. Surface fuels consist of live or dead herbaceous plants, shrubs, litter, and woody material located on the ground. (An option in the planar transect protocol measures ladder fuels up to six feet.) The amount, structure, and continuity of surface fuels influence how fire moves across the landscape. The amount of surface fuel ties directly to how fuel models are used and to the Rothermel fire spread model. The measurement of surface fuels has a strong scientific and conceptual basis, and is easily repeatable and reproducible in different contexts if similar protocols are followed.

Surface fuel amount and structure is easily sampled using a Brown’s transect, a sampling method which is relatively easy to learn and understand as well as be easily repeatable. The simplicity and standardized protocols for data collection and analysis ensures multi-party monitoring team success. The low cost of data collection and the usefulness of the data to determine potential surface fire behavior contributes to the value of these data. In addition, the methods and calculations used in a Brown’s transect are well-tested in various fuel types and will detect changes in fuels over time and space. Packaged computer programs to calculate fuel loading are readily available and tie directly to fuel models.

High levels of coarse woody debris (downed material greater than 3 inches in diameter, abbreviated CWD) can be a negative. Fire hazard including resistance-to-control and fire behavior reach high ratings when large fuels exceed about 25 to 30 tons per acre in combination with small woody fuels of 5 tons per acre or less. Excessive soil heating is likely at approximately 40 tons per acre and higher. Thus, generally high to extreme fire hazard potential exists when downed CWD exceeds 30 to 40 tons per acre. (Brown and others 2003).

The amount of CWD that provides desirable quantities for soil productivity, soil protection, and wildlife needs, without creating an unacceptable fire hazard or potential for high fire severity reburn, is an optimum quantity that can be useful for guiding management actions. For maintaining soil productivity the upper limit of the following ranges is recommended: 5 to 10 tons per acre for warm, dry ponderosa pine and Douglas-fir types, 10 to 20 tons per acre for cool Douglas-fir types, and 8 to 24 tons per acre for lower subalpine fir types (Brown and others 2003). The recommended optimum ranges of CWD quantities should be modified by consideration of other factors such as quantity of small woody fuel, diameter of CWD, landscape level needs, and ecosystem restoration objectives. The CWD optimum quantities for acceptable fire hazard are appropriate when accompanied by small dead fuel loadings of about 5 tons per acre or less. Acceptable CWD quantities are less at higher small fuel loadings (greater than 8 to 10 tons per acre). (Brown and others 2003).

Because CWD amounts at a given site can be expected to change over time with or without management, simulation modeling can help with planning and designing treatments. Predicted quantities of CWD over time vary considerably with fire severity and post-fire treatment, but they also depend on pre-fire stand structure. Site-specific analysis can strengthen decision-making by allowing managers to tailor post-fire treatments to best achieve desired CWD quantities over time. Simulating snag recruitment, falldown, and subsequent decay allows decisions on fuel treatment (salvage harvest and/or surface fuel treatment) to be made in the context of expected future conditions as well as current conditions (Brown and others 2003).

The constraints and concerns with this variable include:

- the Brown’s transect has not been well tested in piñon-juniper woodlands;
- Brown’s transects do not capture fuel continuity very well;
- while Brown’s transects are less time consuming than other methods, they still require field time and many transects in order to represent the fuels properly;
- comparisons of historical surface fuel loadings are hindered by the lack of physical evidence, due to decomposition over time. This is especially true for herbaceous plants, shrubs, litter, and small woody material. Historical photographs and contemporary relationships between overstory density and surface fuels can provide some insight into surface fuel characteristics of past forest structures.

Tree Characteristics

(Score of 13 in Fire and Fuels, 15 in Tree and Forest Structure)

Tree characteristics to be evaluated include: tree density (basal area or trees per unit area), tree diameter at breast height (dbh), tree species, and tree height. These can be used to calculate canopy bulk density (CBD), one of the most useful inputs into fire models.

For each of these variables:

- detailed, scientifically based sampling protocols exist and have been widely used in many different forest types;
- the data these protocols capture is repeatable across space and time, and can easily detect changes to forest structure and composition due to treatments;
- data collection is simple to sample and record, and can be analyzed in many useful ways;
- the collected data can be used to set desired conditions and gauge treatment success; and
- existing historical records exist for comparison with current conditions.

Constraints and concerns include:

- the time and expertise required to perform a common stand exam;
- smaller trees are often missed, depending on the methodology used;
- monitoring is often dismissed in favor of implementation, due to time constraints;
- piñon-juniper and riparian stands differ enough that protocols used in ponderosa pine and mixed conifer must be modified;
- young or small-diameter trees may have been more common historically than we think, due to the lack of physical evidence because of decomposition over time.

Crown-Base Height

(Score of 13 in Fire and Fuels, 11 in Tree and Forest Structure)

Crown-base height is the distance between the ground and the lowest live branch whorl in the tree crown. Individual tree crown-base height values are used to calculate stand canopy base height, which is the lowest height above the ground where canopy fuel is sufficient to initiate a passive crown fire. An increase in canopy-base height often results in a lower probability of starting a passive crown fire. Measurements of crown-base height are repeatable if the same methodology is used. Crown-base height is useful to assess if the restoration/land treatment objectives were met in ponderosa pine and mixed conifer forests. However, crown-base height is not deemed a good indicator of restoration/land treatment objectives in piñon-juniper woodlands because the crowns in these woodlands often reach the ground, and fire spread risk is determined by horizontal crown continuity.

The collection of crown-base height data is manageable and simple to measure and record. If protocols and analysis techniques are standardized, multi-party monitoring team success can be achieved and the cost is relatively low. However, different ways exist to measure crown-base height and calculate canopy-base height. For instance, when an individual tree's crown-base is uneven, one can measure the compacted or uncompacted crown-base height. The compacted crown-base height method requires the person doing the monitoring to visually "transfer" the lower branches to fill holes in the upper portions of the crown, until a full, even crown is created. The uncompacted crown-base height method simply measures the lowest live branch whorl. Therefore, when reporting crown-base height values, one should always identify the method used.

The individual crown-base heights are used to calculate the canopy-base height used in modeling and other calculations. As with measurements on individual trees, several methods are used to calculate canopy-base height at the stand level, with each giving different estimates and affecting fire modeling results. One method averages the individual crown-base height for the stand. Another method uses the lowest crown-base height in the stand. While these two methods are simple, neither are accurate estimates of the canopy-base height. Another method uses the lowest 20th percentile crown-base height for the stand. Fulé and his colleagues (2001) suggest that accounting for the variability of crown-base heights instead of the ”average” condition could simulate more realistic fire behavior, since a crown fire can begin and be sustained in stands that are less than 50% susceptible to crown fire.

Fire behavior models, such as the Fire and Fuels Extension to the Forest Vegetation Simulator (FFE-FVS), estimate canopy-base height by calculating the height at which a minimum defined bulk density of fine fuels is found. Since the estimate of canopy-base height will differ for each of these methods, one should specify the method used. An additional benefit of FFE-FVS is that forest growth can be simulated and changes in fire behavior can be examined over time. Finally, although this modeling software outputs data intended for the fire behavior models, proper use requires some training.

Canopy Cover

(Score of 11in Fire and Fuels, not scored in Tree and Forest Structure)

Canopy cover helps determine how well a fire will move from one tree crown to another. In addition, more canopy cover corresponds to less surface fuel due to the positive interaction between the amount of light and the amount herbaceous growth. In turn, less surface fuel means more dead-and-down accumulation due to a lack of surface fire. Monitoring for this variable produces data that are manageable, easy to record, and sensitive to changes in the system.

However, this variable is difficult to measure, analyze, and use due to the huge variation in results obtained from different sampling methods. A standardized methodology is needed. This variable can be calculated using other tree-related variables (e.g., species and basal area), but the accuracy of these calculations has not been validated.

Understory Cover and Composition (quadrat)

(Score of 8 in Fire and Fuels, not scored in Tree and Forest Structure)

The need to have data on understory cover and composition is important due to concerns with exotic and invasive plants, pre- and post-treatment erosion, and fuel continuity. However, species identification is difficult for untrained field personnel, but effectiveness depends on specificity.

Monitoring for understory cover and composition:

- has a strong scientific and conceptual basis;
- requires relatively simple and standardized analyses;
- produces data and results that are sensitive changes to the ecosystem;
- can be used as a measure of desired conditions and a gauge of treatment success; and
- works in all forest types as well as non-forested (i.e., grassland) areas.

The notable concerns and constraints for this variable are:

- measuring percent cover can be subjective;
- species identification typically requires training and expertise, and is not suited for lay persons;
- identifying all plants to the species level is time consuming; and
- monitoring for species composition depends on ability to identify to species level.

Snags and logs

(Not scored in Fire and Fuels, not discussed in Tree and Forest Structure)

Snags and logs are fuel and will affect how a fire spreads across a landscape. The number and types of snags and logs should be included in stand exams. However, active recruitment and retention of soft snags is probably not a goal that is easily integrated with the reintroduction of fire at a landscape level, particularly in forests that once experienced frequent, low–moderate intensity fire regimes. High fuel continuity from a century of fire suppression will make it difficult to retain large amounts of decayed snags and CWD during the first prescribed fires, i.e., they will burn up. Subsequent fires may retain more snags and CWD because fuel continuity will be reduced, allowing more large woody materials to persist (Stephens and Moghaddas 2005a).

Landscape Patch Characteristics

(Not discussed in Fire and Fuels, Score of 7 in Tree and Forest Structure)

Landscape patch characteristics as used here refers to tree groups and openings on the landscape, and is extensively discussed in GTR-310 (Reynolds and others 2013). Openings are areas with no to very few trees and crown closure of less than 10%. Tree groups are patches with variable tree densities, which include areas of relatively high densities. The distribution of the openings and tree groups should range from random to clustered on the landscape.

The concept of landscape patch characteristics has a strong scientific and conceptual basis, but it is often difficult and/or costly to discern the historical distribution of these variables. Management practices can alter the distribution of groups and openings.

The practical dimensions of groups and openings make this variable difficult to measure and monitor on a large scale. On a landscape level, data collection requires remote sensing techniques to measure these variables, which requires technical expertise. While remote sensing will provide information about the distribution of groups and openings, it will not provide group tree density or tree size information. In this case, on-the-ground measurements are needed, which would require considerable effort for a landscape-level analysis. For these reasons, multi-party monitoring teams would have difficulty collecting the data. Quantifying landscape distribution of groups and openings would be relevant to land managers and easily applied toward adaptive management decisions. Creating groups and openings would meet a restoration management objective, but the effect of groups and openings on fire behavior have not been quantified.

One aspect of landscape patch characteristics not discussed at this workshop was the next level of scale, the effect of treatment projects, typically 300-acre blocks, on fire behavior. When flaming fronts pass where fuels have been treated, a fire's continuity can be disrupted. This "eddy effect" is much like the calm water that is present in a stream after water passes around a rock. After a fire passes such an area, even when driven by strong winds, it takes time for the fire to regain the same intensity it had before hitting the change in fuels (Graham and others 2009). In addition, when intense fires make a major run, one would expect all trees in its path to be severely burned and all of the foliage consumed. However, near the center of the treatment area, a few trees often survive, as well as small seedlings and lower plants. Although the area may be severely burned, the remnant trees and green vegetation will lead to more rapid vegetative recovery compared to adjacent areas where all trees are black (Graham and others 2009).

Workshop Summary

Overall, the participants in this workshop rated these metrics to work most effectively in ponderosa pine and mixed conifer forests, and less so in piñon-juniper woodlands. In addition, the cost of monitoring at the landscape scale is likely to be greater than the project scale due to the greater spatial area being covered and the need to hire professionals to work at this scale doing GIS-related tasks, aerial photography, and ground-truthing. Also:

- While photo points are technically not monitoring variables, they can be effective for showing change over time.
- While stand exams are notoriously expensive and not universally used across the various land management agencies, they are crucial in validating LandSat imaging models. By developing an affordable and standardized format for conducting stand exams, managers can have increased capacity to track changes across forest boundaries. This can be furthered enhanced by developing incentives that encourage private land participation.

Summary

The potential for *passive crown fires* (initiated by the torching of a small group of trees, and probably impossible to avoid completely) is reduced most efficiently by the reduction of surface fuels followed by a reduction of ladder fuels. Reducing surface fuels by prescribed fire is a very effective treatment for reducing the potential for passive crown fires. The potential for *active crown fires* (fire spreading in crown and surface fuels simultaneously, considered serious and usually to be avoided) is reduced most effectively by a combination of mechanical and prescribed-fire treatments, because these treatments can target ladder and surface fuels and intermediate-size trees. However, prescribed fire alone can greatly increase the wind speed needed to initiate a passive crown fire, which effectively reduces stand vulnerability to torching and the transition to active crown fire (Stephens and others 2009). This result is not only supported by modeling of fire behavior, but by empirical studies of wildfires burning through treated stands (Stephens and others 2012). Keep in mind that in many Southwest forests, fuel loading and continuity is so high that prescribed fire without initial mechanical treatment will result in an active crown fire.

Surface fuels, ladder fuels, and crown fuels (in this order of importance) determine both fire intensity and burn severity, and their reduction strongly contributes to fire resilient forests. With this in mind, the first fuel treatments should aim at reducing amounts, distribution, and juxtaposition of surface and ladder fuels (Graham and others 2009). Fuel composition, moisture content, and structure are major determinants of fire behavior and are easily modified by fuel treatments. Their disposition, combined with topography, fire locations, and interaction with fuel suppression activities ultimately determines how a fire behaves (Graham and others 2009).

To evaluate potential fire behavior, measure:

- all trees ≥4 in dbh and saplings >4 ft tall to species, status (alive, standing dead, dead and down), dbh, and total height and height to the base of live crown;
- percentage canopy cover;
- cover (estimate) for grasses, forbs, and shrubs;
- litter, duff, and woody surface fuel using Brown's transects.

From these, calculate:

- trees per acre;
- canopy bulk density;
- litter, duff, and surface fuel mass.

The number associated with almost all of these variables should decrease with treatment; the exceptions are average dbh and height to base of crown. In a restoration treatment, things like grass cover and CWD might also increase, but in a strict fuels treatment, they will decrease. Unfortunately, we do not have general threshold values for most of these variables, so targets are also unknown. That said, since every project is unique, a general target will never be universally applicable.

Modeling tools are available at www.fire.org. Modeling is undoubtedly useful in planning and evaluation, but it is beyond the scope of this report. Evans and others (2011) and Hunter and others (2007) contain good discussions of models for planning and implementing fuel treatments at different scales.

Conclusions

The most appropriate fuel treatment methods vary with forest type and spatial context; a ‘‘one size fits all’’ fuel treatment design does not exist. This is true in part because of spatial context, and also because of the myriad combinations of surface, ladder and canopy fuels, as well as site-specific goals and constraints. Cookbook treatment prescriptions cannot be expected to provide effective fuel treatment plans. Four principles should govern any guidelines for creating fire resilient stands in dry forests: reduce surface fuels, increase the height to the canopy, decrease crown density, and retain big trees of fire-resistant species (Reinhardt and others 2008).

Safford and others (2012) express the opinion that stand-scale quantitative assessments of fuel treatment effects on wildfire severity in frequent-fire forest types hardly merit further effort. That is, rather than spending limited funds on demonstrating yet again that treatments reduce catastrophic wildfire risk, they suggest that future work focus on the ecological outcomes of fuel treatments in burned and unburned forest, such as for species diversity, understory plants, soil conditions, habitat heterogeneity, and the like.

In their natural state (i.e., with recurrent, low severity fire), dry mixed conifer and ponderosa pine forests support classic ‘‘fuels limited’’ fire regimes, where fire-season conditions are nearly always ripe for burning assuming there is enough fuel to carry fire (Safford and others 2012). But in addition to fuel loading, fire weather and fuel moisture can be important to the effectiveness of forest thinning treatments, and the relative importance of these factors varies along a number of environmental and ecological gradients. For example, steeper slopes have a stronger effect on fire severity in treated than in untreated forests. This is due to the influence of heavy surface and ladder fuels, which overwhelm the effects of underlying topography in driving fire behavior. Once the forest is thinned, slope becomes an important driver of fire behavior again (Safford and others 2012).

Large woody fuels (CWD) have little influence on spread and intensity of the initial surface fire in current fire behavior models; however, they can contribute to development of large fires and high fire severity. Fire persistence, resistance-to-control, and burnout time (which affects soil heating) are significantly influenced by loading, size, and decay state of CWD. Unfortunately, methods for estimating and interpreting these fire characteristics are not well established (Brown and others 2003). If management goals include reducing fire danger, then treatments that leave heavy fuels behind in the form of slash or living trees don’t work. Only treatments that allow the possibility of future low-severity fires that manage fuels represent a long-term solution to the problem of unnatural wildfire intensity (Lowe 2006).

Treatments alone do not determine fire behavior. Treatments largely, but not entirely, succeed at minimizing fire severity. Restoration treatments that focus on healthy forest structure allow low-severity fire to easily and inexpensively shape forest conditions in the future, and this, in turn, will reduce the need for future forest restoration thinning. In addition, areas that have recently (within the previous year) been broadcast burned appear to be more effective at reducing fire severity than areas that were broadcast burned years earlier, and large fuel breaks are substantially more successful at reducing fire progress than small fuel breaks (Lowe 2006).

Despite the focus of ongoing research on the effects of fuel treatments, results from studies specifically conducted in riparian areas are limited. Fire is now believed to have been common historically in many riparian areas and, as in surrounding uplands, fire suppression has contributed to fuel accumulation in riparian areas. Yet, for most riparian plant communities, few data are available on fuel loads, fuel characteristics, or fuel distribution (Dwire and others 2016). The effects of wildfire on riparian vegetation have received little research attention, and more effort is needed on this topic.

Research is a vital cog in the fire management system, but we do not need to wait for all research to conclude; we know enough right now to implement effective fuel treatments. Fuel treatments should be used to reduce fire severity and intensity instead of fire occurrence. The range and variation of historical stand and landscape composition and structures should be used as guides but not targets. The primary goal of fuel treatment should be to create landscapes in which fire can occur without devastating consequences. Once these conditions have been achieved, wildfire need not be as vigorously suppressed and can itself play a role in maintaining these landscapes (Reinhardt and others 2008).

Enough uncertainty exists that adaptive management is crucial. Fire behavior and forest ecology are both complex, and some effects or restoration treatments will inevitably not be those predicted. For that reason, managers must incorporate adaptive management techniques such as evaluating the results of past treatments during the planning of new ones (Lowe 2006).

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