Effectiveness of Shaded Fuel Breaks on Fire Severity: Literature Review and Analysis

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San Bernardino National Forest Keenwild Station left untouched after the 2013 Mountain Fire burned over it, due to encircling fuel break and defensible space improvements. Credit: USFS.

Executive Summary:

Shaded Fuel Breaks are a vegetation management strategy for reducing wildfire intensity where surface fuels (*e.g.,* sticks, leaves, branches and downed logs) and ladder fuels (*e.g.*, shrubs, tall grasses, saplings, and lower branches of trees) are reduced or removed while keeping most of the mature trees and upper canopy intact. These efforts reduce fuels a fire has access to, reducing fire severity and making it easier to suppress, while keeping intact the plant communities in the area and reducing regrowth of hazardous vegetation via shade. Shaded fuel breaks closely mirror the historic fire regime of pre-colonization California, where frequent, low-severity fires reduced surface and ladder fuels, preventing a build-up of fuels that would have resulted in a high-severity, destructive wildfire. In a fire-suppressed landscape, those same ecosystem processes must be done manually to ensure that the landscapes of Marin County are healthy and fire-resilient.

This white paper examines the existing scientific literature on shaded fuel breaks and how these treatments impact overall fire behavior and intensity. Shaded fuel breaks are a technique used around the world, but special emphasis is placed on studies in California in order to most accurately understand the impacts of these treatments in Marin County. The paper first establishes how fire behavior in California works in hardwood, conifer, and mixed woodlands and forests, with a special emphasis on vertical behavior and wind patterns; next, it provides an understanding of the impacts of shaded fuel breaks; finally, it investigates how that behavior differs across treated and non-treated landscapes to determine the overall risk-reduction benefits of shaded fuel treatments. 25 peer-reviewed scientific studies, along with experience of firefighters , prescribed and cultural fire practitioners, and land managers were collected and analyzed to create a cohesive picture of wind and ember spotting behavior in shaded fuel breaks.

Findings:

Shaded fuel breaks are an effective method to reduce fire intensity and rate of spread, which increases the chance of suppressing the fire, increases the likelihood of structure survival, and creates more time for residents to evacuate. By reducing surface fuels (primarily detritus and dead plant material) and ladder fuels (primarily invasive understory plants) while keeping the upper canopy and large trees intact, shaded fuel breaks dramatically reduce the likelihood of a fire becoming severe, and also improve ecological outcomes. Shaded fuel breaks do not substantially increase wind speed or ember spotting potential because of their structure, which more closely resembles a pre-colonial coastal California ecosystem with frequent, low-severity, fires.

Fire Behavior in California: Vertical Growth, Severity, and Weather Patterns

Much of California's landscapes are adapted to high frequency, low severity fire, which created heterogenous and biodiverse ecosystems that rarely burned at high severity. These frequent fires, caused by lightning and Indigenous Californians, reduced surface and ladder fuels and occasionally killed larger trees, creating light availability for new growth and snag habitat (Wilkin, et al., 2021; Dagely, et al., 2018). Fires are driven by surface fuels first and foremost, the fuels closest to or on the ground that allow a fire to start and move outwards in space. Fires can only move into the upper canopy of trees if 1) the convective and radiant heat from the surface fire is so great it "torches" trees, or 2) there is a continuity of fuel, sometimes called "ladder fuels", that allows a fire to climb upwards into the canopy. In either case, surface fuels are still a driving force of the fire, because a fire in the crown or canopy of a forest still requires massive convective and radiant heat from the surface fire below in order to sustain and spread (Thomas and McAlpine, 2010). Without heavy surface fuels, a crown fire will drop back down to the surface.

Another way fires can spread is through ember spotting, where hot embers are thrown by wind ahead of the flaming front, creating opportunities for ignitions ahead of the actual fire. Long distance ember spotting virtually only happens in high-severity crown fires, because embers in a surface fire aren't typically large enough, hot enough, or thrown by winds far enough to create long-range risk (Albini, 1983). Studies have shown that the genus *Eucalyptus* presents some of the greatest ember spotting risk of any vegetation when fire reaches the canopy because of its large pieces of peeling, oil-laden bark, so much so that the Australian government has created its own "Bark Hazard" tool when modeling Eucalyptus bush fires, which projects that under high winds, burning Eucalyptus embers can be thrown up to 20 miles away (Hines et al., 2010). This demonstrates the need for greater management and/or removal of Eucalyptus in Marin County, where it is one of the most pervasive and well-established invasive species in the region.

In addition to fuel, weather is a critical factor in understanding fire behavior in California. For the purpose of this paper, wind behavior and fuel moisture are identified as the most relevant weather conditions because they are the metrics that can reasonably be impacted by fuel treatments. Wind is typically measured in the fire context as the so-called "20-foot wind speed", or the wind speed and direction measured at 20 feet above the canopy (National Wildfire Coordinating Group). However, wind speed decreases logarithmically as it reduces in altitude, and the friction of the canopy can reduce wind speed by an average of 50% (Albini, 1979). The fire itself can also create its own wind patterns, both an updraft from the hot air rising, and an indraft from air in surrounding areas rushing in to replace it. Crucially, this effect increases in intensity with fire severity, with the strongest in and updrafts occurring in high-severity crown fires (National Wildfire Coordinating Group). Wind speed and direction is also clearly impacted by large-scale weather events and topography, but those forces cannot be impacted by landscape-level fuel treatments. Shaded fuel breaks minimize the factors that would contribute to higher wind speeds during a fire because they combine a strong canopy that slows down approaching wind, with a greatly reduced chance of high-severity fire that would pull an updraft (Ibid).

Fuel moisture also impacts fire behavior, with drier surface and ladder fuels contributing to hotter, more severe fires. Fuels become more moist when dew or precipitation drops on the understory, and dry out when heated and ventilated by wind and sun. Shade from overstory cover can keep fuel moistures higher by shading the fuels and catching and condensing moisture from fog and the marine layer. Shaded fuel breaks have been shown to substantially increase fuel moisture and relative humidity in the forest microclimate, because the most significant factor is the shade and transpiration from an intact canopy (Pickering, et al., 2021).

Understanding Impacts of Shaded Fuel Breaks

Shaded fuel breaks aren't designed to stop a fire, but to substantially reduce the rate of spread and intensity to allow more time for people to evacuate, provide a greater chance of structure survival, and give firefighters more favorable conditions to attack and suppress the fire (Baijnath-Rodino et al., 2023). Shaded fuel breaks seek to keep a fire out of the canopy by substantially reducing surface and ladder fuels, while leaving the overstory intact to keep fuel moisture high, protect and restore ecosystems, and reduce regrowth of understory vegetation that would necessitate constant treatment. Shaded fuel breaks are a well-established treatment used across the world, primarily in the Wildland-Urban Interface (WUI), and have been shown both in computer simulations and real-world conditions to reduce fire intensity and rate of spread when properly designed (Agee, et al., 2000; Low, et al., 2023; Seto, et al., 2022).

A few researchers have expressed concerns that shaded fuel breaks may allow wind to move more quickly through the stand, possibly increasing fire intensity, rate of spread, and ember spotting. In particular, Bradley, et. al. (2016) is often cited as an example of the ineffectiveness of shaded fuel breaks. However, this position is generally considered outside the scientific mainstream. In fact, most fire ecologists and land managers agree that fuel reduction projects dramatically reduce the destructiveness of wildfires. (Martinson and Omi, 2013; Bigelow and North, 2012).

Bradley et. al (2016) correlates lands with fewer protections against logging with higher severity fires across broad swaths of the western US. However, this research's application to shaded fuel breaks and other fuel reduction projects is limited because it largely references commercial logging and conflates the practice with fuels reduction projects, despite the prescriptions having several crucial differences. Commercial logging, particularly clearcutting, harvests the largest trees and leaves the small saplings, shrubs, and cut branches, while shaded fuel breaks protect the largest, healthiest trees and focus on the removal of invasive species and dead and down fuels. Additionally, the removal of the canopy in commercial harvesting allows wind to move through the stand faster, while a largely intact canopy in a shaded fuel break slows wind down (Russell, et al., 2018). Effectively, clearcutting and commercial logging maximize available surface fuels, create stronger winds, and reduce shade to dry fuels out faster. This is the opposite of what a shaded fuel break does, and so it is not surprising that the two prescriptions would have diverging impacts on fire intensity. Assuming the correlation identified in the paper is caused by the forces the authors assert, it does not actually contradict the efficacy of fuels reduction projects, but rather reaffirms what researchers already know about the role of surface fuels and canopy heterogeneity in fire behavior.

Clearcutting from commercial logging on the Lewis and Clark River, Oregon. (Walter Siegmund, Wikimedia Commons)

Shaded fuel break in the French Meadows Restoration Project, Tahoe National Forest. (Roger Bales, Sierra Nevada Research Institute, UC Merced)

Comparing Treated and Non-Treated Landscapes for Fire Severity

After establishing the relevant considerations and fire science, it is now possible to compare the effectiveness of shaded fuel breaks and the "do nothing" state of untreated landscapes. This assessment will not only help the Marin Wildfire Prevention Authority (MWPA) understand the effectiveness of treatments, but also identify best practices and techniques to minimize fire intensity and maximize ecological benefit.

As fuel breaks have increased in popularity over the last 30 years, research and case studies have shown their effectiveness at reducing fire spread and intensity. For example, in 2023, the Hope Fire in Fresno County started in late July, carried by strong winds, and moved quickly through dry fuels and steep terrain. The rate of spread and fire intensity was so great that CAL FIRE air attack resources were mobilized to protect structures and communities. When the fire crested the ridge, it hit the White Deer Vegetation Management Project, a 200-ft wide linear fuel break constructed in 2019 to reduce fuel levels that had been as high as 20 feet. According to CAL FIRE Battalion Chief Alejandro Sanchez, the fuel break was decisive in stopping the fire because it reduced the fire's intensity, allowing firefighters to attack it directly and slowing the rate of spread. "The fuel break had a tremendous positive effect in minimizing fire spread and allowing our ground personnel and equipment access to fight the fire," he said. The fire, which was gaining in speed and intensity and had the potential to run up the entire hill, was stopped at only 3.7 acres (CAL FIRE, 2023).

Another example of shaded fuel break effectiveness can be found in the Mountain fire, the subject of a 2014 US Forest Service research paper. In July 2013, the Mountain Fire burned in the foothills of Mt San Jacinto in the San Bernardino National Forest in mixed timber-chaparral fuels, aided by dry winds and heavy fuel loads. It destroyed 23 structures and prompted the evacuation of 6,000 people. The fire moved so quickly and burned so intensely that it grew to over 20,000 acres in just three days, and was declared contained at 27,351 acres only after significant rainfall. The Forest Service studied the effectiveness of seven different fuel treatments in reducing fire severity in 2,112 acres of treated land that burned in the fire. It found that while some treatments performed better than others, all methods of up-to-date fuel treatment reduced fire severity and structure loss, and that the treatments were effective for up to seven years. Areas in the Bonita Vista fuel break burned at a quarter of the severity compared to adjacent untreated areas. In particular, fuel breaks aligned with prevailing wind directions significantly reduced fire severity and worked synergistically with other treatments including defensible space and prescribed burning to significantly reduce fire severity.

A combination of defensible space and an encircling fuel break saved the USFS Keenwild Station and surrounding buildings, and was so effective that crews left the buildings unattended, and was untouched despite the fact that station was at the top of a hill, and the fire burned at high severity in every direction (USFS, 2014).

The research paper also identified ways to enhance fuel breaks and treatments, some of which the MWPA has implemented, and some which may be considered in the future. The orientation of fuel breaks, both linear and polygon, was found to be crucial in combating wind driven fires approaching communities. For example, the Greater Novato Shaded Fuel Break, Greater Ross Valley Shaded Fuel Break, and San Anselmo/San Rafael Fuel Reduction Zone have all been strategically placed to align with prevailing wind patterns to provide maximum protection to surrounding communities. Polygon-based fuel reduction zones should also maximize heterogeneity of temporal, spatial, and biological diversity, because they must be able to withstand a fire coming from many directions, while a linear fuel break is designed to withstand fire from one direction. Additionally, coordinating fuel treatments with defensible space improvements, such as what the MWPA is doing with private land coordination and defensible space inspections, is critical in maximizing the efficacy of fuel treatments, because they work in conjunction to first reduce, and then eliminate, flame lengths as a fire approaches a home. The paper also recommends anchoring fuel reduction projects around historic fire footprints, which already have reduced fuel loads from the past fires to work in coordination with fuel reduction projects, which the MWPA may consider as an additional analytical planning tool.

One possible area of greater study for the MWPA is understanding the role of riparian “fuel bridges” as identified in the Mountain Fire. In fuel treatment projects, riparian areas are often less intensely managed due to environmental, logistical, and regulatory requirements, which leave areas of higher fuel loads within a treatment area that a fire can cross (Van de Water and North, 2011; USFS, 2014). While it isn’t always practical to treat every riparian area to minimize fire risk, careful planning and mapping of these areas can allow managers to create buffer zones around them, and allow first responders to prioritize those areas for evacuation and initial attack.

Fuel breaks have been shown in these and many other case studies to improve outcomes in a fire, whether that be reducing severity, improving structure survivability, or enhancing safety for people evacuating and firefighters attacking the fire (Agee, et al., 2000; Low, et al., 2023; Stephens, et al., 2022). A comparative computational analysis found that if fuel treatments had been implemented in Paradise, California, residents would have had twice as much time to evacuate from the Camp Fire, potentially saving dozens of lives (Seto, et al., 2022). Computer modeling, empirical studies, and ecological analysis all verify real-world scenarios as well. A 2013 meta-analysis of 1,200 publications covering 62 types of fuel reduction treatments found that fuel treatments in forested stands on average reduce canopy volume scorch (a measurement of severity) from 100% to 40%, and reduce flame lengths by two feet. Virtually every treatment option was considered highly effective, with even the least effective treatment option reducing fire effects 70% of the time. The meta-analysis specifically names surface fuel treatments as “of primary importance in influencing treatment effectiveness” because of their central role in reducing crown fire (Martinson and Omi, 2013).

Conclusions and Recommendations

Not only is there clear and convincing evidence that shaded fuel breaks reduce fire severity, intensity, and rate of spread, but there is also a wealth of studies showing how best to implement these projects to maximize efficacy and ecological benefit. As noted above, shaded fuel breaks mimic many of the natural disturbance cycles that coastal California ecosystems have relied on for tens of thousands of years, primarily through high-frequency, low-severity fire. In the last century and a half, humans have artificially removed these natural processes through fire suppression, contributing to increased fire danger and decreased resilience and biodiversity (Wilkin, et al., 2021; Dagely, et al., 2018; North et al., 2022). Returning Marin County's ecosystems to a more fire resilient state helps all inhabitants of Marin, human and not. As the 2013 meta-analysis shows, the single best predictor of fuel treatment effectiveness is residual tree diameter, showing that healthy, resilient ecosystems with fewer, widely spaced large trees are most effective at protecting Marin residents and communities (Martinson and Omi, 2013).

With a better understanding of wind and ember spotting behaviors in these fuel treatment areas, it is also possible to conclude with certainty that fuel reduction treatments do not increase fire effects in any measurable way. Wind is generated from above the canopy, and the massive friction of an intact canopy is the primary reducer of wind speed. Thus, treatments that reduce surface fuels but maintain the canopy do not substantially increase winds. Further, because surface fuel reduction makes crown fire so much more unlikely, and ember spotting is a phenomenon virtually only seen in crown fires, these treatments substantially reduce ember spotting potential.

Based on the scientific review and analysis of the relevant literature, the following recommendations are made to maximize the efficacy of current and future fuels treatments:

- Understand, map, and incorporate disturbance history (such as fire history and return interval departure) and fuel type into future vegetation management efforts, particularly through "anchoring", or the strategic placement of fuel breaks on a known safe point where suppression efforts can be launched. Data should also be shared with incident managers to help identify predicated areas of extreme or moderated fire behavior (USFS, 2014)
- Focus on recruitment and retention of the largest, healthiest trees and support native revegetation efforts in areas impacted by fire, landslide, and invasive species removal (Martinson and Omi, 2013).
- Build temporal, spatial, and biological diversity into treatment plans to create more heterogeneous landscapes, particularly in fuel reduction areas where a fire may approach from multiple angles (USFS, 2014).
- Consider the role of untreated riparian areas as "fuel bridges" across fuel treatments as seen in the 2013 Mountain Fire, and incorporate ways to mitigate the elevated risk into planning efforts (Van de Water and North, 2011; USFS, 2014).
- Incorporate long-range spotting risk from Eucalyptus trees into risk assessments, and more aggressively remove Eucalyptus in the WUI (Hines, et. al 2010).

- Incorporate prescribed fire into vegetation management projects, as it has been shown to be some of the most effective and longest lasting fuel treatment techniques, particularly when combined with hand thinning, while also providing ecological benefits (North et al., 2021)
- Invest in research to determine where ecosystems are being or have recently been type converted due to fire suppression or invasive species colonization, and incorporate their restoration into vegetation management projects (Hagmann et. al, 2021).

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