Forest Service
U.S. DEPARTMENT OF AGRICULTURE

Rocky Mountain Research Station

Science You Can Use Bulletin

MARCH/APRIL 2023 | Issue 59

Can Fuel Treatments Change How a Wildfire Burns Across a Landscape?

In a congressional hearing in September 2021, USDA Forest Service Chief Randy Moore said the following about the "state of emergency" in America's forests: *"We must actively treat forests. That's what it takes to turn this situation around. We must shift from small-scale treatments to strategic science-based treatments across boundaries. It must start with those places most critically at risk. We must treat 20 million acres over 10 years. Done right in the right places, treatments make a difference."*

Soon after, Congress authorized $2.4 billion for fuels-related projects from 2022 to 2026. With the new investment, the Forest Service released a 10-year plan to treat 50 million acres in the West above current levels.

Against this policy background, a team of scientists from the USDA Rocky Mountain Research Station (RMRS) and Tall Timbers Research Station completed a synthesis for the Joint Fire Science Program on the current state of knowledge on landscape fuel treatment effectiveness. The resulting report, "Effectiveness of Fuel Treatments at the Landscape Scale: State of Understanding and Key Research Gaps," is intended to guide managers in planning effective fuel treatments across landscapes.

A prescribed burn after thinning in a ponderosa and Jeffrey pine forest on the Lassen National Forest, California. The recent fuel treatment effectiveness synthesis showed that treating multiple fuel layers reduced fire spread and severity. USDA Forest Service photo by Sharon Hood.

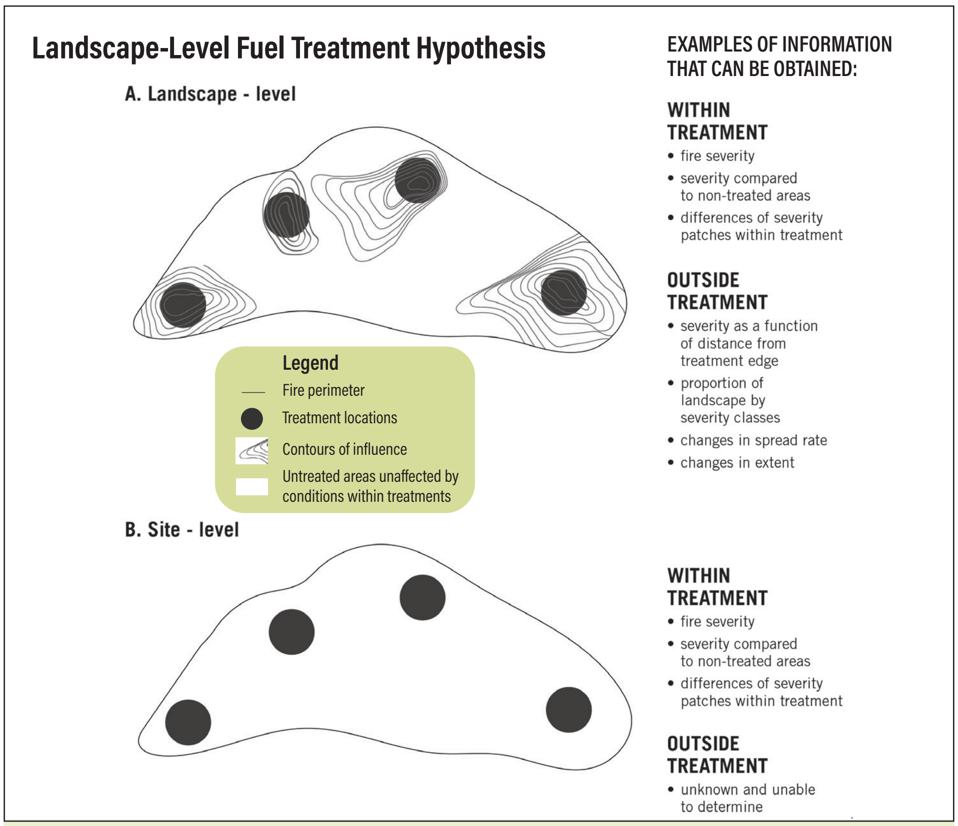
Theresa "Terrie" Jain, an RMRS research forester (now scientist emeritus) with the Forest and Woodland Ecosystems Program and the project lead, says the lack of a clear understanding and agreement of what is meant by the term "landscape" underscores the need for the synthesis.

"We found that in the science papers, researchers used the term landscape, but they never defined their landscape. We found that the term was used in the title or as a keyword, but often the paper did not really address the landscape," Jain says. "Even though fire is a landscape process, few researchers are really doing landscape-level analysis."

Jain says we know that fuel treatments work at the *site level*—

meaning that treatments alter fire behavior and effects within treatment boundaries. For example, we can measure fire severity within treatments and compare it to nontreated areas. Understanding whether treatments are effective at the *landscape level* involves assessing whether the effects of treatments on fire attributes, such as fire extent, rate of spread, or severity, are apparent outside of the treatment footprint. Did the fire slow down or become less severe after interacting with a treatment? This is a much more difficult task.

Jain collaborated with a large team of scientists to conduct the literature synthesis. After assessing thousands of papers, the team identified 127 studies that met their criteria for addressing landscape fuel treatment effectiveness. Most focused on forested landscapes in the West. The team broke the studies into three groups based on their approach and methodology: empirical studies, simulation studies, and case studies.



The landscape-level effect hypothesis (A) assumes that fuel treatments can affect wildfire behavior outside of their footprint (i.e., in untreated areas). To test this hypothesis, a study must quantify a link between conditions within fuel treatments and some metric of fire behavior or effect outside of the treatment footprint. Asymmetric contour shapes reflect the notion that fire behavior outside of treatment boundaries will also be influenced by multiple characteristics of an area. White areas represent untreated areas that are unaffected by conditions within the treatments. Scenario A can be interpreted as a prediction of the landscape-level effect hypothesis, that if true, then a spatial relationship exists between within treatment and outside of treatment conditions during a wildfire. Scenario B would not provide the necessary information to test the landscape-level effect hypothesis and is instead site-level; inference of treatment effect is restricted to within treatment boundaries. Figure from McKinney et al 2022 Fire Ecology paper.

SUMMARY

By all measures, wildfires in the western United States are becoming more extreme. Fires are growing larger and burning more intensely, and suppression costs are spiraling upward. Maximizing the effectiveness of fuel treatments at the landscape scale is key given limited resources and the inability to treat all areas likely to burn in a wildfire.

Research forester Theresa Jain with the Rocky Mountain Research Station collaborated with fellow Station scientists along with colleagues from research institutions across the country to synthesize existing scientific literature on landscape-scale fuel treatment effectiveness in North American ecosystems through a systematic literature review.

The team identified 127 studies that addressed the fuels treatment effectiveness using simulation modeling, empirical analysis, and case studies. The studies show that fuel treatments reduced negative outcomes of wildfire and often promoted beneficial wildfire outcomes. Weather conditions influenced the effectiveness of treatments, and effectiveness lessened over time following treatment, pointing to the need for maintenance treatments. The studies also emphasized the importance of treating multiple fuel layers (canopy, ladder, and surface) to reduce fire spread and severity. Fuel treatments also contributed to fire suppression efforts by reducing costs and facilitating suppression activities, such as fireline construction.

The science team has developed a fuel treatment effectiveness framework with measurable criteria to better understand how stand-level fuel treatments collectively contribute to broader landscape-level fuels management goals.

MANAGEMENT IMPLICATIONS

- Fuel treatments slowed the rate of spread and shifted crown fires to surface fires, and fire severity decreased inside fuel treatments.
- Fuel treatments created fire suppression opportunities by reducing the rate of fire spread and creating anchor points that facilitated line construction, structure protection, and spot fire suppression.
- Fire suppression activities were critical for a fuel break to be effective, as less than 1% of the wildfires are stopped by a fire break alone.
- Treatments are effective for a finite length of time, pointing to the need for maintenance treatments.
- Use of optimization algorithms to determine placement and/or timing of treatments led to greater effectiveness compared to other methods.
- Simulation studies confirmed that treatments of a greater extent, or amount of treated area, can reduce wildfire impacts, and studies pointed to a threshold of about 30% beyond which further treatments result in diminishing returns.

Overall, the studies showed that fuel treatments were effective in changing wildfire behavior (e.g., shifting a fire from a canopy to a surface fire), reducing negative wildfire outcomes, and, in some cases, promoting beneficial outcomes. Weather conditions influenced the effectiveness of treatments, and effectiveness lessened over time following treatment, pointing to the need for maintenance treatments.

The studies also emphasized the importance of treating multiple fuel layers (canopy, ladder, and surface) to reduce fire spread and severity.

Mastication treatments in Klamath National Forest, California. A synthesis of 127 studies demonstrated that landscape-scale fuel treatments reduced negative outcomes of wildfire and in some cases promoted beneficial wildfire outcomes. Courtesy photo by Morgan Varner.

However, Jain says research reports often buried that message in comparisons of treatment types.

"Researchers often say mechanical treatment followed by prescribed fire works better than mechanical or prescribed fire alone. Well, of course it does—mechanical treatments reduce ladder and canopy fuels while prescribed fire deals with surface fuels. You're treating more fuels by combining treatment types," Jain says. "You can't inform a manager about which treatments are truly effective without indicating which fuel layers have been affected."

The synthesis teams also found that fuel treatments created fire suppression opportunities by reducing the rate of fire spread and creating a safe space that facilitated fireline construction, structure protection, and spot fire suppression. One of the more interesting findings was the role of suppression resources in the effectiveness of fire breaks.

"By design, fire breaks are supposed to stop a fire," Jain says. "There's lots of science that support fire breaks, and yet they don't work unless you have suppression efforts. A fuel treatment can only be as effective as the suppression that goes along with it."

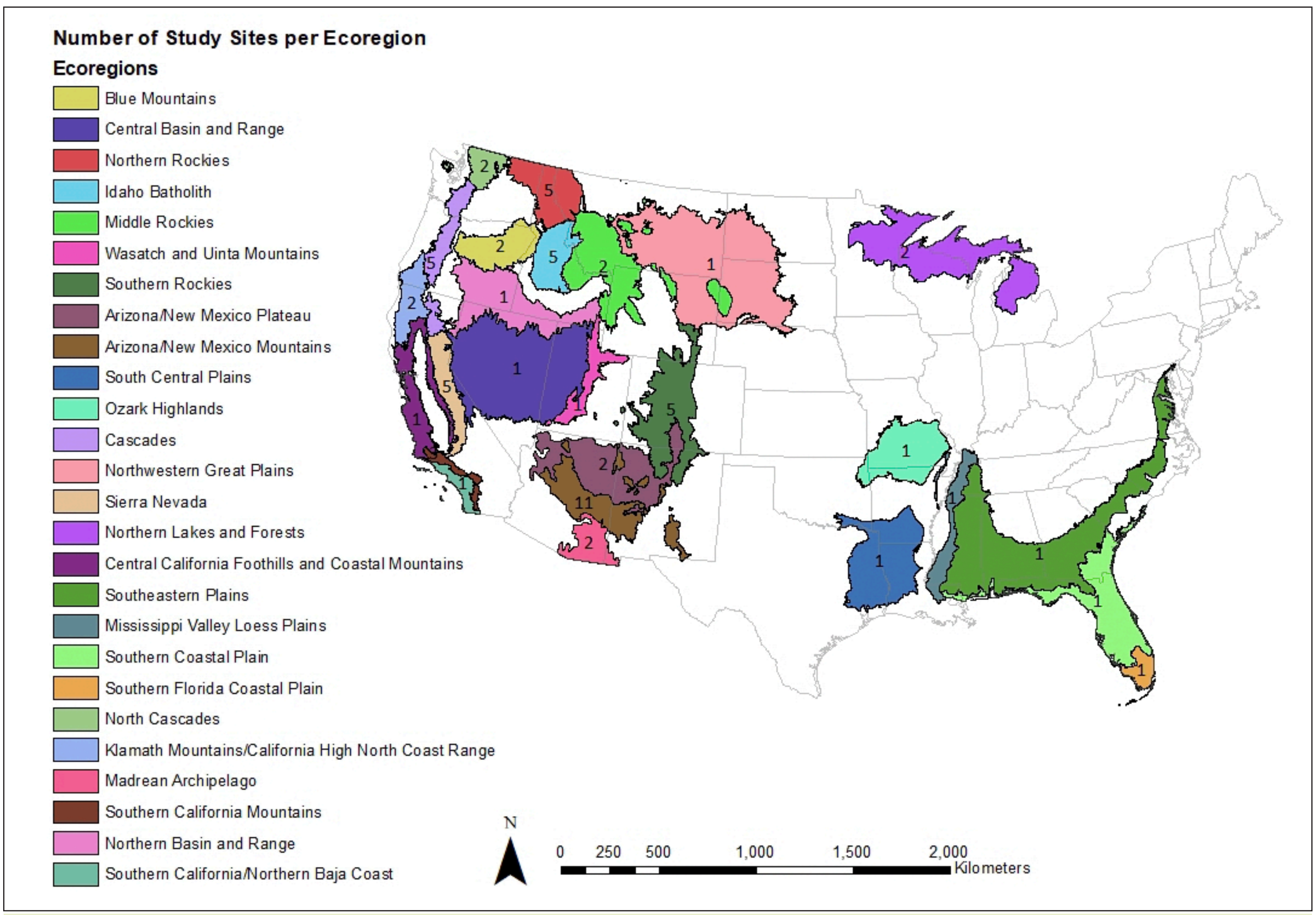
In the next few sections, we dive into the findings for each of the synthesis groups (empirical, simulation, and case studies) and discuss take-home messages that can guide landscape-scale fuel treatment planning and implementation. Finally, we describe a fuel treatment effectiveness framework that the synthesis team developed with criteria that managers can use to assess how well fuel treatments reduce fuel hazards and then evaluate the fire effects outcomes of actual fires.

Natural Experiments

Shawn McKinney, an RMRS ecologist, and the empirical studies synthesis lead, says that setting up a "gold standard" empirical field study of landscape-level treatment effects is virtually impossible.

"Say we have a few small watersheds in an area, and we go in and treat 20 percent of one watershed, then 50 percent of another, and 75 percent in another," says McKinney. "We will need each of those replicated in two to three more watersheds to have any sort of statistical power in our analysis. Then, we have to sit back and hope a wildfire hits all of our treatments. The likelihood of this occurring is very small. Patience and persistence will be needed, much like the approach to long-term monitoring of ecological systems."

Yet, fires do regularly test fuel treatments, setting up "natural experiments" that can provide valuable information for fuels planning and implementation. In one study, researchers were able to quantify landscape-scale fuel treatment effectiveness in a natural experiment in a fire (the 2013 American Fire in



Ecoregions where landscape-scale empirical studies were conducted. Figure from McKinney et al 2022 Fire Ecology paper.

KEY FINDINGS

- A synthesis of 127 studies demonstrated that landscape-scale fuel treatments reduced negative outcomes of wildfire and in some cases promoted beneficial wildfire outcomes.
- Treating multiple fuel layers reduced fire spread and severity.
- Simulation studies showed that fuel treatment extent, size, placement, timing, and prescription influenced the degree of effectiveness.
- Empirical studies provided evidence that fuel treatments were effective at reducing the rate of spread, progression, extent, or severity of actual wildfires both within and outside of treated areas.
- The recency of treatment implementation was a key factor in how effective treatments were in changing fire behavior. The case studies indicated that the length of time needed before retreatment depended on site productivity, plant species traits, and initial fuel removal, which all contribute to how a site might reburn in a subsequent wildfire after treatment.
- Several case studies showed that as fires moved into treated areas, even if they were burning at high intensity, fire intensity lowered enough that spot fires were not as common or not as far-ranging from the main fire.
- More extreme fire weather led to greater wildfire extent but not necessarily less treatment effectiveness relative to untreated scenarios.

Crews cut juniper trees in southern Utah. RMRS scientists and colleagues synthesized 176 studies about fuels projects to provide the current state-of-knowledge on landscape fuel treatment effectiveness. USDA Forest Service photo by Sharon Hood.

California) that burned through a well-monitored fireshed (lands around a community where wildfire ignitions could cause fires to spread into the community). The fire had been recently treated using SPLATS (strategically placed landscape area treatments)—an approach for fuel treatment placement that uses a regularly spaced array of fuel treatments with the aim of reducing fire spread. Researchers compared fire severity in the SPLATS fireshed and that of an adjacent untreated fireshed.

"This is one of the rare examples we came across from the empirical side where you had somewhat of an accidental experimental design," McKinney says. "It was as much of a direct comparison as you could have in nature."

The SPLATS fireshed had 18% of its landscape treated prior to the fire, which resulted in only 11% of the area burning under high severity, compared to the untreated control area in which 26% burned under high severity.

Other empirical studies have confirmed that landscape-scale fuel treatments can reduce the rate of fire spread, progression, extent, or severity of proceeding wildfires. When the proportion of treated area increased, fire severity

When the proportion of treated area increased, fire severity declined both within and outside of treated areas.

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Wildfire Simulations

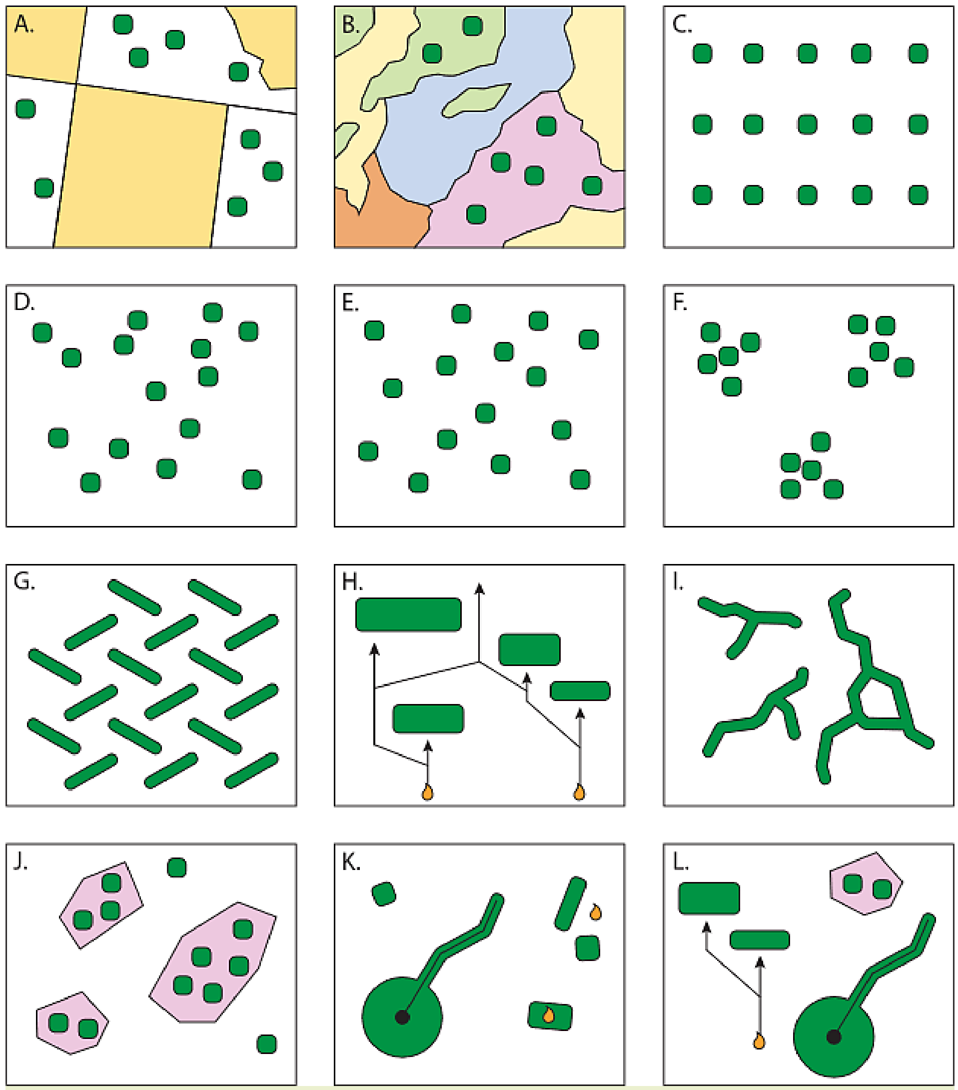
Researchers and managers have developed a variety of fire behavior models for simulating fire spread and behavior on modeled landscapes. These models provide a quick and efficient way to test the effectiveness of different fuel treatment variations, with the caveat that there's always some level of inaccuracy in the data used to represent the landscapes and how well model outputs reflect actual real-world wildfire characteristics.

"There's a lot of useful information in these studies just in terms of guidance or planning at the landscape scale and how you would implement treatments from the outset," says Jeff Ott, a RMRS research biologist and the simulation study synthesis lead. "The context here is that you want to do some fuel treatment on the landscape, but there are limitations on how much can be done, how much funding is available. These studies highlight some elements to consider."

Some simulations used optimization algorithms to place treatments at strategic locations that are most likely to intercept and slow the spread of large fires. The optimization algorithms generally (but not always) outperformed alternative placement strategies, such as expert-guided placement and SPLATS.

"The idea behind most treatment optimization algorithms is that if you're trying to prevent fire spread to certain areas, or otherwise reduce fire impacts across the landscape, then there are ways you can optimize for that based on what the models say about how fires are likely to behave," Ott says.

He says that algorithms can help managers group and arrange treatments for easier implementation.



Representation of fuel treatment placements used in fuel management and simulation studies: A. regular; B. random; C. dispersed; D. clumped; E. regularly spaced, strategically placed, area treatment (SPLAT) array; F. linear fuel breaks, often associated with land features to protect defined resources; G. constrained by property boundaries; H. prioritized by vegetation type or fuel load; I. prioritized by other landscape features, such as slope and aspect; J. defensible fuel profile zone, with defensible space around communities and roads or near locations with potential for ignition events; K. treatment optimization model, utilizing fire spread models to predict strategic placement locations; L. expert placement utilizing various strategies based on expert opinion.

Simulation studies confirmed that treatments of a greater extent, or amount of treated area, can reduce wildfire impacts, and studies pointed to a threshold of about 30%, beyond which further treatments result in diminishing returns.

A Grounded Perspective

Case studies were a compilation of direct observations of fire by firefighters, line officers, and forest managers. They provided observations on how fire behavior interacted with existing fuel treatments, and how those interactions then affected wildfire management decisions they made in real time, such as deployment of suppression resources.

"Case studies offer the on-the-ground perspectives of managers on the value of fuel treatments—when they worked, when they didn't work, and what were the primary factors that influenced whether they worked?" says Alexandra Urza, a RMRS research ecologist and the case study synthesis lead. "Experiential knowledge from experts on the ground was really valuable to integrate into the broader synthesis."

Several case studies described wildfires that transitioned from high intensity to moderate, then to low intensity as they entered past forest treatments. Managers reported that treatment areas experienced more surface fires with lower flame lengths, and slower rates of spread, as compared to untreated areas. Several case studies showed that as fires moved into treated areas, even if they were burning at high intensity, fire intensity lowered enough that spot fires were not as common or not as far-ranging from the main fire.

"Changing a fire from a crown fire to a surface fire makes it much easier to manage, and, in most cases, those lower-intensity, lower-severity fires have more beneficial ecological outcomes," Urza says.

The recency of treatment implementation was a key factor in how effective treatments were in changing fire behavior. The case studies indicated that the length of time needed before retreatment depended on site productivity, plant species traits, and initial fuel removal, which all contribute to how a site might reburn in a subsequent wildfire after treatment. In addition, strategic placement of treatments, in relation to other treatments and older wildfires, and alignment with prevailing winds and topographic firebreaks provided much more "bang for the buck" from the fire managers' perspective.

The case studies showed that fuel treatments provided opportunities for suppression resources that wouldn't have existed if areas hadn't been treated. For example, the reduced rate of spread in treatments created space and time for fireline construction, safety zones, structure protection, and spot fire suppression.

"Changing a fire from a crown fire to a surface fire makes it much easier to manage, and, in most cases, those lower-intensity, lower-severity fires have more beneficial ecological outcomes,"

- Alexandra Urza, RMRS research ecologist

"Firefighters felt safer carrying out burnout operations in treated landscapes because they knew they could control fire behavior better," Urza says. "They also used treated areas as anchor points—places where they built line off of that they could then use to directly fight the fire."

A New Framework

Sharon Hood, a RMRS research ecologist, and Morgan Varner, the director of research at the Tall Timbers Research Station in Tallahassee, Florida, have been working with their synthesis colleagues to develop a framework to better understand how stand-level fuel treatments collectively contribute to broader landscape-level fuels management goals.

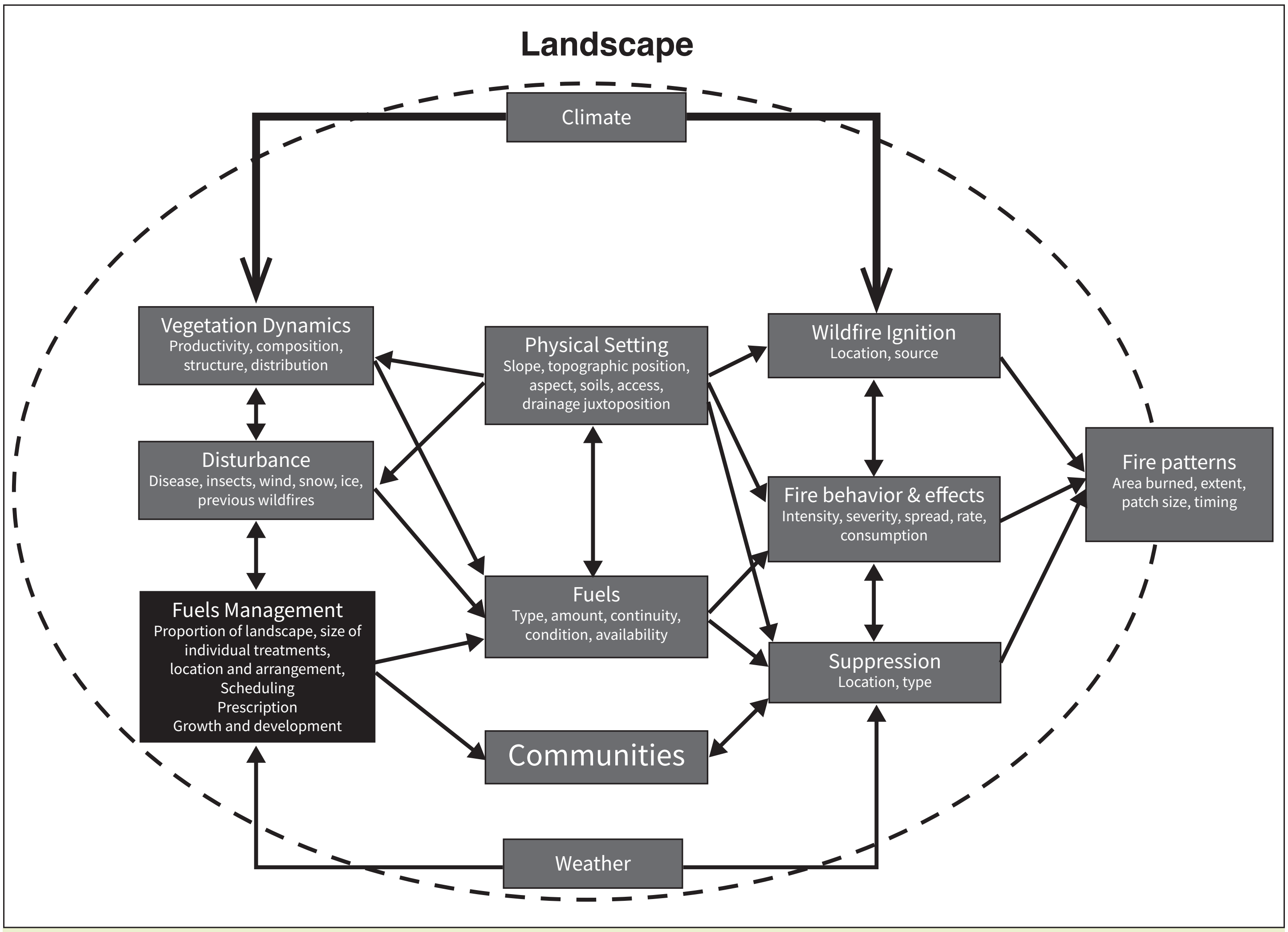
"Currently, national wildfire and fuel treatment summaries report acres burned and acres treated," Hood says. "But we need more information about how areas burned to determine if treatments were effective. What effects are we seeing? How much did we reduce potential severity?"

Hood says this is important because fire effects may be positive, negative, or neutral—so burning can result in desirable and undesirable outcomes.

"Reporting only simple metrics like acres burned implies only a negative effect, but we know some fires do good ecological work," Hood says. "We're not managing for acres treated or burned. We're managing our landscapes to be more resilient to disturbances."

The synthesis team has proposed criteria that managers can use to determine the effectiveness of fuel treatments in reducing fuel hazard and then quantifying fire outcomes of actual fires. Their fuel treatment effectiveness framework provides a road map for analyzing how a treatment altered fuels, and then how those changes affected actual wildfire behavior and effects.

"The framework acknowledges the complexity of fuels and fire," says Varner. "And that's clearly how most landscapes are. They're not clean little, small units where fire only propagates within the unit."



Conceptual model of factors that influence fuel treatment effectiveness.

Reducing fuels and altering fuel arrangement moderates fire hazard, or the potential fire intensity. Fire hazard is driven by fuels, weather, and topography, which together determine fire behavior. Since managers have no control over the latter two aspects, they work to reduce fuels or alter fuel arrangement to reduce fire hazard. The fuel treatment effectiveness framework above shows several measurable stand- and landscape-level attributes managers can use to describe fire hazard.

Within the framework, evaluation of the effectiveness of a fuel treatment tested by a wildfire is based on observed fire behavior and effects on environmental and social attributes. In this way, how a fire burned and how the vegetation changes become the focus rather than just reducing total area burned or increasing acres treated. Extreme weather and/or topography can have an outsized influence on fire behavior and effects, so Hood and colleagues have proposed dashboard indicators that put individual fires in the context of the cumulative effects of fuels treatments and wildfire over large areas.

"We propose attributes that could be used with minimal effort to document treatment effectiveness in a more systematic way," Hood says. "We have to tie discussions of treatment types back to how it changed fuel layers because it's

Fuel Treatment Effectiveness Framework

Metrics outlined below can be used to quantify realized (i.e., actual) and potential effectiveness of stand and landscape fuel treatments. Attributes are dictated by pre-identified objectives and landscape boundaries; not all attributes will be relevant for every evaluation. Hazard state attributes describe the condition of fuels from objective quantification of actual vegetation and fuels and the subjective prediction of potential fire behavior and effects (i.e., severity) based on best-available modeled output. Realized fuel treatment effectiveness is based on actual fire behavior and effect attributes and should be compared against no-treatment and alternative-treatment scenarios.

Evaluation of hazard	**Stand attributes**	**Landscape attributes**
Hazard state	Data-derived, actual: Surface fuel load Canopy base height Canopy bulk density Fire-resistant trees and species Modeled output, potential: Fire Behavior Fuel Model Potential flame length Potential rate of spread Potential fire type[1] Potential severity	Fire Return Interval Departure distribution Structural stage/Age class distribution Fire Regime Condition Class (% of classes) Treatment extent (% treated) Potential flame length distribution Potential fire type[1] distribution Potential severity distribution
Evaluation of fuel treatment effectiveness	**Stand attributes**	**Landscape attributes**
Environmental and ecological attributes	Fire severity Fire size Strategic point protection ability Fire progression/rate of spread	Total area burned Extent burned (%) Characteristic fire severity (% or BA killed) Characteristic patch size (%)
Social attributes	Fire suppression opportunities Suppression costs	Structures lost Evacuations (# days and people) Suppression costs Smoke production Smoke exposure

[1]Surface, torching, crowning

not enough to say we treated this many acres. We have to be able to say exactly how that changed fuel loading or changed canopy fuels because that's what is driving fire behavior."

"Our approach acknowledges that fire and fuels at the landscape scale are really complex, and then proposes some interesting ways to look at it," Varner says. "It's certainly not the last word—we're hoping it stimulates conversation."

Next Steps

The synthesis team says that existing research contains useful information for fuel treatment planning, but gaps remain in underrepresented ecosystems and geographic areas (most studies are in ponderosa pine and Douglas-fir forests in the West), as well as on topics such as cost-benefit analysis and fuel treatment longevity.

Jains says improving understanding of the factors underlying the effectiveness of landscape-level fuels treatments is needed to prioritize and optimize responses to the current wildfire and fuels management situation.

"Combining research with local on-the-ground knowledge can inform the design and implementation of fuel treatments with the most bang for your buck," Jain says. "And more effective fuel treatments result in reduced costs and risks for suppression operations and improved ecological outcomes."

FURTHER READING

Jain, Theresa B.; Abrahamson, Ilana; Anderson, Nate; Hood, Sharon; Hanberry, Brice; Kilkenny, Francis; McKinney, Shawn; Ott, Jeffrey; Urza, Alexandra; Chambers, Jeanne; Battaglia, Mike; Varner, J. Morgan; O'Brien, Joseph J. 2021. Effectiveness of fuel treatments at the landscape scale: State of understanding and key research gaps. JFSP PROJECT ID: 19-S-01-2. Boise, ID: Joint Fire Sciences Program. 65 p.

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SCIENTIST PROFILES

The following individuals were instrumental in the creation of this Bulletin.

THERESA JAIN is an emeritus scientist with the Forest and Woodland Ecosystems Program of the Rocky Mountain Research Station. Her research focus is on integrating silviculture research and management applications.

SHARON HOOD is a research ecologist with the Rocky Mountain Research Station. Her research focuses on how fire affects trees and ultimately forest dynamics.

SHAWN MCKINNEY is an ecologist with the Rocky Mountain Research Station. His research focuses on understanding the impacts of human perturbations in forested communities to inform management in these systems.

JEFFREY OTT is a research biologist with the Rocky Mountain Research Station. He studies effects of fire and invasive species on plant communities, post-fire seeding, and ecological genetics of native plants, primarily in dryland ecosystems of the Intermountain West.

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MORGAN VARNER is the Director of Research and a Senior Scientist at Tall Timbers Research Station in Tallahassee, Florida. He coordinates Tall Timbers' research collaborations aimed at improving understanding of fire behavior and predictions of fire effects on plants and animals.

SCIENTIST PROFILES (COLLABORATORS)

ILANA ABRAHAMSON is an ecologist with the Rocky Mountain Research Station who leads the Fire Effects Information System (FEIS) team of the Fire Modeling Institute in the Fire, Fuel, and Smoke program. FEIS is an online database of research syntheses on species and ecosystems and their relationships with fire.

NATHANIEL ANDERSON Nathaniel (Nate) Anderson is a research forester with the Rocky Mountain Research Station, in Missoula, Montana. Nate's research is focused on forest management and blends silviculture, operations research, and economics.

MIKE BATTAGLIA is a research forester with the Forest and Woodland Ecosystems Program of the Rocky Mountain Research Station. His research focuses on restoration strategies for ponderosa pine and dry mixed conifer forests, forest stand dynamics post-disturbance, various methods of hazardous fuels reduction treatments, and developing silvicultural strategies that incorporate the uncertainty of climate change.

JEANNE CHAMBERS is an emeritus scientist with the Maintaining Resilient Dryland Ecosystems program of the Rocky Mountain Research Station. Her current research focuses on (1) developing an understanding of the factors that determine ecological resistance to invasive species and that affect ecological resilience to disturbances like wildfire, and (2) using that information to develop effective management and restoration approaches.

BRICE HANBERRY is a research ecologist with the Maintaining Resilient Dryland Ecosystems program of the Rocky Mountain Research Station. Her research focuses on analysis and management of disturbance effects, including fire and fire exclusion, climate change, and land use on terrestrial ecosystems, natural resources, and wildlife at multiple scales, with a particular focus on open oak and pine ecosystems.

FRANCIS KILKENNY Francis Kilkenny is a research biologist with the Maintaining Resilient Dryland Ecosystems program of the Rocky Mountain Research Station. His research focuses on the adaptation of plant populations to local climates and successional dynamics in post-fire restoration and fuel-treatment seedings. He uses these data to develop tools for restoration seed-sourcing in changing climates.

JOSEPH O'BRIEN is a research ecologist with the Southern Research Station. His research focuses on fire science, specifically the spatial interactions among wildland fuels, fire behavior, and fire effects.

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