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The role of fuel treatments during incident management

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Abstract

Background Forest fuel reduction treatments are intended to mitigate negative impacts from wildland fires, protect communities, and support firefighting. Understanding fuel treatment use is important for evaluating treatment effectiveness, which, in turn, can inform the strategic planning and design of treatments. A relatively understudied aspect of fuel treatments is how existing fuel treatments are incorporated into firefighting (i.e., incident management). In this paper, we explore how fuel treatments are used by firefighters and Incident Management Teams during fires to inform the broader conversation of designing fuel treatments and assessing fuel treatment effectiveness.

Results Through interviews with wildland fire and forest managers (e.g., Incident Commanders, Agency Administrators, Fire Management Officers, and Fuels Planners) on seven western wildfire incidents during 2020 and 2021, we investigated how forest fuel treatments were utilized during firefighting. We found that treatments were considered and used during incidents in various ways, including to conduct burnouts, for direct modification of fire behavior, as access points for firefighters or equipment, or as components of contingency plans. Most interviewees said treatments provided additional options and flexibility in decision-making, enhancing both firefighter and community safety. For instance, treatments were used to reduce overhead hazards to firefighters and, in some cases, were prepared to serve as safety zones.

Conclusions The decision to use a fuel treatment was based on several conditions, including the time since the treatment was implemented or maintained, treatment location, incident conditions, and personnel dynamics within the Incident Management Team or local forest unit. We explain what these findings mean in the context of wildland fire decision-making literature. We also provide recommendations for using fuel treatments to support wildfire incident management.

Keywords Wildland fire, Fuel treatment, Incident management, Decision-making

Resumen

Antecedentes Los tratamientos de reducción de combustibles forestales están orientados a mitigar los impactos negativos de los incendios, a proteger a las comunidades y a ayudar en el combate de incendios. El entender el uso de los tratamientos de combustibles es importante para evaluar su efectividad, lo cual, a su vez, puede informar sobre el planeamiento estratégico y diseño de los tratamientos. Un aspecto relativamente poco estudiado de los tratamientos de combustibles es cómo los tratamientos de combustibles existentes son incorporados en el combate de incendios (i.e., manejo de incidentes). En este trabajo exploramos cómo los tratamientos de combustibles son usados por los brigadistas de incendios y los grupos de manejo de incidentes durante los incendios para proveer de información para un más amplio debate sobre el diseño de tratamientos de combustibles y determinar su efectividad.

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Resultados Mediante entrevistas con brigadistas y manejadores del recurso forestal, (i.e. comando de incidentes, administradores, manejadores de incendios y planificadores del manejo de combustibles), relevamos información sobre siete incidentes de incendios en el oeste de los EEUU durante 2020 y 2021, e investigamos cómo el tratamiento de los combustibles era utilizado durante el combate de esos incendios. Encontramos que los tratamientos fueron considerados y usados durante estos incidentes de diferentes maneras, incluyendo los contrafuegos para modificar directamente el comportamiento del fuego, para abrir puntos de acceso para combatientes o ubicar equipos, o como componente para planes de contingencia. La mayoría de los entrevistados dijeron que los tratamientos proveyeron de opciones adicionales y flexibilidad en el proceso de decisión, lo que incrementó la seguridad tanto de los combatientes como de la comunidad. En ese sentido, los tratamientos fueron usados para reducir los peligros imponderables para los combatientes y en algunos casos, fueron usados y preparados para servir como zonas seguras.

Conclusiones La decisión de usar tratamientos de combustibles fue basada en diferentes condiciones, incluyendo el tiempo desde que estos tratamientos fueron implementados o mantenidos, la ubicación de estos tratamientos, las condiciones de los incidentes, y la dinámica del personal dentro de *Team* del Comando de Incidentes o de la unidad forestal local. Explicamos qué es lo que estos resultados implican en el contexto de la literatura referida a la toma de decisiones en el caso de incendios forestales. También proveemos de recomendaciones para el uso de tratamientos de combustibles para apoyar el manejo de incidentes de incendios.

Introduction

Given the increase in larger, more severe, and more frequent wildfires in the western United States (U.S.) and other locations around the world, there is a need for ongoing research on how fuel reduction treatments influence fire effects, behavior, and suppression (e.g., Finney 2001; Stephens et al. 2012; Vaillant and Reinhardt 2017). Reducing wildfire-related risks to communities, critical infrastructure, and watersheds is a primary focus of the U.S. Department of Agriculture (USDA) Forest Service (USFS), making understanding the effectiveness of fuel treatments a timely issue (USFS, 2022). In this paper, we explore how forest fuel treatments are used by firefighters to inform the broader conversation of understanding fuel treatment use, design, and effectiveness.

The term forest fuel treatments, sometimes referred to as “treatments” herein, describes any mechanical, silvicultural, or burning activity intended to alter fuel load, type, or arrangement (Reinhardt et al. 2008). Fuel treatments can reduce the negative effects of wildfire either through altered fire behavior or improved containment opportunities (Collins et al. 2010; McKinney et al. 2022). Treatments designed to alter fire behavior typically meet other ecological and social objectives as well, including improved wildlife habitat, restored ecological structure and function, and protection of highly valued structures and natural resources (Collins et al. 2010).

Forest fuel treatments most often include prescribed fire and mechanical treatments (Agee and Skinner 2005; Martinson and Omi 2013; Jain et al. 2021). Prescribed fire involves the deliberate use of managed fire to reduce surface fuels and sometimes increase canopy base height (Agee and Skinner 2005; Jain et al. 2021). Mechanical treatments include any treatment where specific trees and other vegetation are selected for removal or retention (Jain et al. 2021). One of the primary mechanical treatments is thinning, which commonly involves the removal of smaller trees and brush while retaining larger, more fire-resistant tree species to restore an open canopy structure (Prichard et al. 2021). Thinning and burning together typically have the most significant effect on mitigating fuel loads and fire behavior compared to either treatment done separately (Martinson and Omi 2013; Kalies and Yocom Kent 2016; Prichard et al. 2021). Each forest stand is suited to a different kind of prescription to determine which fuel treatment will achieve desired management goals (Prichard et al. 2021).

Fuel treatments also can be designed to support the safe and successful response to wildland fire incidents (Barnett et al. 2016), which is the focus of this paper. Fuel treatments can be used to strengthen the suitability of features to serve as anchor points (e.g., roads, ridges, rocky features, or water bodies) from which firefighters construct fire containment lines (Agee and Skinner 2005) or used to expand the proactive application of beneficial fire (North et al. 2021). Treatments might facilitate burnouts, where fire managers deliberately set fire inside control features to consume unburned fuels (NWCG, 1996). In addition, treatments can help firefighters create staging areas and support contingency plans. Treatments can also be used to build or connect larger fuel breaks, which are a type of fuel treatment designed to be used in conjunction with wildfire suppression resources. Fuel breaks are typically placed along ridges or roads, or in valley bottoms and can serve as anchor points for indirect attack, staging, and burnouts; in conjunction with suppression and other fuel treatments, they can reduce the intensity and effects of fire (Agee et al. 2000; Syphard et al. 2011).

Treatments of all types typically require regular maintenance and follow-up treatments to continuously meet fuel reduction objectives (Barnett et al. 2016; Prichard et al. 2021). Multiple studies report that the longer it has been since an area was treated, the less effective a fuel treatment will be, noting that the diminishing rate of effectiveness depends on location, climate, and ecology (Agee and Skinner 2005, Martinson and Omi 2013, Barnett et al. 2016, Kalies and Yocom Kent 2016, and Jain et al. 2021). Fuel break effectiveness has been found to depend on accessibility, fire size and resource availability, maintenance, and proximity to roads (Gannon et al. 2023; Moghaddas and Craggs 2007; Syphard et al. 2011). Fuel treatments are typically most effective when applied across larger spatial extents, although this can be complicated due to access, funding limitations, land management designations, and as land managers try to balance ecological and social goals across landscapes (McKinney et al. 2022; North et al. 2015).

Different strategic frameworks can guide fuel treatment placement. Arranging fuel treatments according to the Potential Operational Delineations (PODs) framework (Thompson et al. 2022a) can include fuel treatments designed intentionally to facilitate fire management objectives such as holding a fire at the boundaries of a particular polygon; these boundaries, in other words, can be created intentionally as possible future fire containment lines (Buettner et al. 2023). Other strategies more explicitly focus on altering fire behavior and effects as fire moves through a landscape (Finney 2001). These approaches can be combined.

Existing scholarship reveals inconsistency in how forest treatments are evaluated for effectiveness (McKinney et al. 2022; Vorster et al. 2023). Some efforts determine fuel treatment effectiveness based on how the treatment alters fire severity, behavior, rate of spread, acres burned, flame length, and resources lost (McKinney et al. 2022). Hood et al. (2022) recommend explicit consideration of both hazard reduction and post-fire outcomes, in terms of both social values and ecological indicators, to understand fuel treatment effectiveness. They also note that there must be consideration at both the stand and at the landscape level of outcomes. The USFS and Department of Interior Fuel Treatment Effectiveness Monitoring (FTEM) application is one example of a national effort intended to document the effectiveness of fuel treatments. Effectiveness is evaluated against a variety of fire behavior metrics based on the treatment's objective as defined in planning documents, like flame length, rate of spread, intensity, and area burned, as well operational metrics like if the treatment was used for initial attack, and how well the treatment facilitated wildfire suppression (FTEM 2023). While FTEM offers an opportunity to evaluate treatment effectiveness, submitting detailed information, such as how the treatment contributed to fire management decisions, is optional. This highlights the need for improved methods to capture treatment effectiveness beyond tracking changes in fire behavior (Hood et al. 2022).

Multiple metrics should be used to evaluate fuel treatment effectiveness depending on treatment objectives, use, and fire outcomes (Hood et al. 2022; Vorster et al. 2023). The design of a fuel treatment meant to facilitate firefighting during an incident may differ from the design of a fuel treatment meant to alter fire behavior. A fuel treatment could also be designed to meet multiple objectives. Fuel treatments can be used to alter fire behavior and to support firefighting, which may have varying objectives, ranging from suppression in some areas to managing wildfire to achieve desired outcomes in others. Thompson et al. (2022b) argue that when fuel treatments are used to support the reintroduction of beneficial fire, metrics like reducing the rate of spread are not appropriate treatment evaluation metrics; indeed, ecologically robust fuel treatments may increase the rate of spread while reducing fire severity, residence time, and heat flux to soils. In relation, the literature notes that suppression costs are an unreliable metric for fuel treatment success because they depend on a host of variables, many of which are unrelated to fuel treatments (Vaillant and Reinhardt 2017).

Because fire behavior can be unpredictable, another consideration is whether fuel treatments should be evaluated against both their intended purpose and their de facto use, and how to evaluate treatments considering variable fire behavior and weather conditions. For instance, if direct attack, or direct and immediate suppression of a fire, is desirable and is an option, the utility of more peripheral treatments during that fire might be irrelevant. But, if direct attack were not feasible or desirable, given landscape or weather conditions, those peripheral treatments might present new opportunities to use nearby features, like roads or ridgelines, for an indirect attack. Assessments of treatment effectiveness typically are made based on the degree that wildfires encounter them and the rate of overlap. If treatments are designed to facilitate suppression and support contingency planning, however, then assessments need to look beyond fuel treatment and fire interactions to understand fuel treatment effectiveness.

The scientific literature recognizes the challenge of evaluating the effectiveness of fuel treatments given the many interacting factors that influence wildfire behavior, strategic decisions, and outcomes (Martinson and Omi

2013; Hood et al. 2022; McKinney et al. 2022; Vorster et al. 2023). The landscape of designing and evaluating fuel treatments also is related to the complexity of defining the fire management problem, which looks across risks and benefits of fire in both the short and long term (Schultz et al. 2019a). The decision to use a particular method to assess fuel treatment effectiveness can depend on how the assessor views wildfire and wildfire management objectives (e.g., fire as an ecological process to restore, as an existential risk to manage, or both). Political pressures and human biases also may influence how an agency measures fuel treatment effectiveness; agencies typically use evaluation metrics that they can easily measure and are of particular importance to policymakers and elected officials (Biber 2009). Evaluation metrics also have multiple uses, including accountability to political overseers, creation of behavior incentives, or communication with various key groups. Consequently, the metrics used to evaluate fuel treatment effectiveness will necessarily be complex, and some measurements may not fully capture a treatments' potential effectiveness or incentivize optimal design and strategic placement.

There have been a number of studies on fuel treatment use in operational contexts (see, for example, Gannon et al. 2023; Hankin et al. 2023; Harris et al. 2021; Moghaddas and Craggs 2007; Syphard et al. 2011; Urza et al. 2023). Many of these studies are place-specific and include primarily quantitative analysis. To contribute to this still-emerging area of scholarship, this study addresses this topic through qualitative interviews to provide an in-depth look at the contextual factors that influence fuel treatment utilization during incidents. We investigated the following questions, using a case study methodology described in the next section: (1) How do wildland fire and forest managers incorporate fuel treatments into firefighting, and (2) What are the key factors impacting how fuel treatments are considered and incorporated into firefighting?

Methods

To understand the value of existing fuel treatments in an incident management context, we conducted 47 semi-structured interviews across seven case studies of different wildfire incidents. Focusing on incidents (or cases) was necessary to effectively draw comparative conclusions for fuel treatment integration during incidents, as opposed to gathering perspectives and knowledge across random incidents without context or triangulation of perspectives (Yin 2014). Triangulation involves using more than one source of data to cross-check findings.

To guide our study approach, we first conducted scoping interviews to help us understand how treatments are generally perceived during fuel treatment design and planning as well as during active firefighting. We interviewed two staff members in each western USFS Region (Regions 1–6) who had experience in both fuel planning and firefighting; individuals were recommended to us by USFS regional fuel leads, who also were interviewees in some cases. In addition to reviewing foundational literature, these initial interviews were conducted to help inform our study design and our interview questions, given these individuals could speak to both firefighting and fuel planning considerations across the West. We also built off insights from these interviews to help us identify our case studies. Findings from this initial set of interviews are not included in this paper but can be found in a previous report (Greiner et al. 2023).

We focused on relatively larger, and longer duration fires that account for most of the area burned annually, suppression workload, and impacts; further studies may benefit from exploring smaller acreage fires. To select case studies for the 2020 fire season, we asked our initial set of interviewees for recommendations of fires that occurred in 2020, primarily on USFS land, that may have interacted with fuel treatments, including treatment locations that burned during the fire or places where treatments were considered or utilized during incident response. We also compiled recommendations from USFS regional fuel leads and USFS fire management advisors in our network. For the 2021 fire season, in addition to the aforementioned approaches, we also referenced final fire extents from Wildland Fire Interagency Geospatial Service Group when evaluating possible case studies. Our compiled list of recommended wildfires was then assessed by our project team using multiple criteria (Table 1).

All fires were cross-checked with Inciweb and the FTEM database to ensure they were in proximity to a variety of fuel treatments and that they occurred primarily on USFS land. Fire selection was also narrowed down based on confirmation from forest leadership and timely staff responsiveness. Table 2 provides a summary of our seven case studies and information about each fire.

The questions in our interview guide were organized into two primary sections: first, fuel treatment consideration and use during the incident, and second, fuel treatment design. The first section included, for example, questions about how the interviewee came to learn about the existing fuel treatments on the landscape, their communication experiences around fuel treatments during the incident, how treatments affected decisions and eventual outcomes, and what characteristics of treatments made them useful or effective. The second set of questions focused on fuel treatment design and included questions about the forest's strategic approach to planning fuel treatments and pre-incident planning analytics

Table 1 Criteria for the selection of case studies (this structure was adapted from a study by Mackenzie et al. 2012)

Selection criteria category	Criteria
Meets basic study parameters: 2020 and 2021 wildfires where fuel treatments were used (or not used) in some way during incident response	• Fire footprint primarily on western USFS managed land (USFS Regions 1–6) • Proximity to existing USFS fuel treatments (based on referrals or the FTEM application) • Treatment interactions recorded in FTEM during the time of our sampling period (this criterion was preferred but not necessary due to variable data input)
Research relevancy and opportunity: Opportunity for case diversity and study richness	• Minimum of 50,000 acres and 30 days duration • Variety of fuel treatment uses during suppressions (e.g., enhanced containment opportunities, provided firefighter safety, changed fire behavior, treatments not used) • Fires that offer opportunity for regional diversity • Fire recommended by multiple informants (2021 fires were also selected via online database)
Pragmatism: Practicality of successfully completing interviews	• Support from local Forest Supervisor for staff to participate in the study • Willingness, interest, and availability of staff to participate • Relatively simple regarding authority and management (e.g., limited joint command and or extreme weather incidents)

Acronyms used in Table 1: *USFS* United States Forest Service, *FTEM* Fuel Treatment Effectiveness Monitoring

Table 2 Case studies and fire information

Case study (incident name)	Fire year	U.S. National Forest and State	Total acres burned	No. of interviewees
Cameron Peak	2020	Arapaho and Roosevelt, Colorado	208, 913	10
Bighorn	2020	Coronado, Arizona	119,978	5
Cub Creek 2	2021	Okanogan-Wenatchee, Washington	70,186	6
Lick Creek	2021	Umatilla, Washington	80,421	8
McCash	2021	Six Rivers, California	94,962	4
Trail Creek	2021	Beaverhead-Deerlodge, Montana	62,013	7
Windy	2021	Sequoia, California	97,528	7
			Total	**47**

and tools, for example. Depending on the interviewee's role and expertise, not all questions were answerable by all interviewees. Interview questions are available upon request.

Interviews were conducted in accordance with an approved Colorado State University's Institutional Review Board human subjects research protocol. For each case study we aimed to interview at least one Agency Administrator, in charge of the local land management and for setting incident response objectives, one Incident Commander, responsible to Agency Administrators for all incident wildfire response activities, and one local Forest Fuels Planner. We spoke with three to five additional people recommended by interviewees as being key individuals knowledgeable about our research questions. These additional roles included, for example, Fire Management Officers, in charge of fire activities within their area, and Operations Section Chiefs, in charge of firefighting operations during an incident. Our interviewee sample was mostly federal employees, but some interviews of non-federal personnel took place when such personnel had critical knowledge about fuel treatments during the incident. One limitation of our study is that some individuals did not respond to interview requests or were not available during our study's time frame. We stopped sampling when we had no more responses and when we approached data saturation (i.e., we were not hearing any substantially new information on our primary research questions) (Saunders et al. 2018).

Interviews were voluntary and ranged from 45 and 90 min. All interviews were recorded and transcribed by a third-party transcription service and then reviewed by our research team. We used Dedoose, a qualitative analysis program, to analyze our data. Dedoose allowed us to identify themes in our interviews by assigning "codes" to segments of interview text. We then aggregated and organized excerpts for these themes across interviews. To establish our codes, we began with overarching concepts related to our key research questions (e.g., "treatment characteristics" and "barriers and facilitators" of using fuel treatments). We then coded for sub-themes emerging from the data for these categories, such as "ecological parameters" under "barriers and facilitators". The codebook was developed by the first author. It was tested and refined by the second and third authors until agreement was reached on most codes applied to the text (some new and less-common codes emerged later in the coding process). This is an appropriate and well-established methodology for analyzing qualitative data (Campbell et al. 2013). We report on our findings organized by each research question and supply illustrative quotes in our results to give examples of data excerpts. Findings are aggregated from all case studies unless otherwise noted. To protect interviewee confidentiality, we do not associate interviewee's roles with specific fires. We also do not point to specific treated areas by name.

Results

How do wildland fire and forest managers incorporate fuel treatments into firefighting?

Across all our case studies on individual fire incidents in the west, wildland fire and forest managers actively considered existing fuel treatments during firefighting. Interviewees were generally positive about the utility and value of treated areas during fire response. We report here on the most common ways wildfire and forest managers incorporated fuel treatments into firefighting. First, most interviewees emphasized that treatments are frequently considered when fire management personnel assess initial firefighting strategies on the landscape. Across all cases, nearly all interviewees highlighted the importance of increasing options and flexibility in decision-making to improve both firefighter and community safety. Many noted that the primary benefit of using fuel treatments during firefighting is their ability to provide additional strategic options. As one McCash Fire interviewee put it, "[Fuel treatments] allow us to get ahead of the game... It gives us more options and it gives us more opportunities to be successful."

The second most common way treatments were used during incident response was to conduct burnouts. In all case studies, we heard multiple instances where firefighters intentionally lit fuels adjacent to fuel treatments to leverage various elements such as time, space, or resources. We note that our interviewees interchangeably used the terms burnout and backfire, though, by definition, these operations are different (NWCG, 1996). Another common use of fuel treatments mentioned in all our case studies (but not by all interviewees) was that treatments directly moderated fire behavior in some places. Interviewees said this helped protect values at risk, decreased structure loss or damage, and in some places enhanced time efficiencies. As one interviewee from the Lick Creek Fire explained, "We were able to move really fast because there wasn't a whole lot of vegetation to manipulate... most of that treatment had already been done to the level that you needed to have that road system ready to burnout and be successful with. If it hadn't been [treated], I don't think we would've had time to pull enough vegetation out of there to prep it for burnout…with the resources that we had." Another common benefit of using treatments across all case studies was that using existing treatments reduced the amount of time and resources required to prepare an area for a given use, thus allowing responders to reallocate resources to another area of the fire.

In some cases, the fire did not directly reach the treated area. In those circumstances, treatments often provided more viable safety zones or were prepped to establish anchor points, as access points for firefighters or equipment, as staging areas for resources, or used as components of contingency plans. A few interviewees noted that treated areas offered greater visibility for spot fires. Several interviewees emphasized that in these indirect cases, treatments offered greater firefighter safety due to reduced fuels and potential fire behavior, making these places more secure or feasible for firefighters and equipment. For example, an interviewee on the Trail Creek fire explained, "That shaded fuel break along the top [of the Montana, Idaho border along the continental divide], we used that for a travel corridor because we knew it was safe. It wasn't the best safety zone because it wasn't completely devoid of fuel, but it was a pretty good safety zone. I knew that fire was going be a lot lower intensity in there." Several interviewees affirmed fuel treatments are often used indirectly during firefighting, yet fuel treatment effectiveness reporting focuses only on areas where fuel treatments directly interacted with wildfires. As one interviewee said, "I can't speak for everybody and how and what they put into those databases [FTEM] … but I believe it's only where the wildfire interacts. That might be the missing link to all this, even if the fire doesn't interact, that fuel treatment is a place that the operational resources had an option to immediately show up and look at as a potential option... We use the PACE model [Primary, Alternate, Contingency, Emergency], whether it's due to resource shortages, the time of year, or type of fire behavior, oftentimes we have to go to these more indirect strategies, and that's the first thing we're looking for is, what's out there on the ground that we can even have the option to work from." Table 3 includes additional quotes from interviewees regarding fuel treatment utility during incidents.

A few interviewees mentioned there can be adverse outcomes from using treated areas during incident management. First, some noted that treated areas are not always safer for firefighters. Sometimes recently thinned areas have more slash on the ground, which creates more tripping hazards, they said. Also, a couple of interviewees expressed how incomplete treatments can exacerbate fire behavior particularly if slash piles have not been followed

Table 3 Interviewee quotes regarding fuel treatment utility during incidents

"On the Cameron Peak fire, they had some large-scale, proactive fuels reduction projects in place, and without them, we would not have been as successful as we were. Looking at how big the fire was in those days of catastrophic growth; it could have been worse if the fuel treatments hadn't been in place. They were the only things we had to anchor and build upon."—Cameron Peak Fire
"Treatment of that area to thin it out and restore more natural conditions, healthier conditions, did in fact, during the Windy Fire, help to moderate the fire behavior....The fire did drop to a ground fire in there, and fire crews were able to manage it much easier in that area due to those fuel treatments. Had those treatments not been done there, with reasonable certainty we would've probably lost all the Monarch giant sequoias in there and the trail itself."—Windy Fire
"It allowed firefighters to get in there and engage more aggressively than if we didn't have those fuel treatments in place... it impacted the amount of time and the ability to do work, as well as the effectiveness of the work that they did, because the pre-work had already been put in."—McCash Fire
"We used [fuel treatment] information to help make sense of how we were going to prioritize getting into some of the interior stands that were a huge concern for the Agency Administrator and Sequoia task force... they had good data on which groves had received good treatments and which hadn't. We definitely used that as we were prioritizing which groves we could get into and have the best outcome with the least amount of effort."—Windy Fire
"We used road systems; those happened to align exceptionally well with fuel treatments, and it was very clear that the Umatilla National Forest had done extensive work in that area.... I felt like we were in a good spot, [that] we were ahead of the curve instead of behind the curve, that we could control [the fire] on our terms. Even though we had just taken [command of] the fire, I thought, 'Okay, we've got this.'"—Lick Creek Fire

with prescribed fire. Several interviewees also commented that under extreme fire behavior, even the most ideal fuel treatments are difficult to utilize.

Finally, most interviewees explained that treatments are typically designed with interdisciplinary teams and as such are often planned with multiple goals in mind, like hazardous fuel reduction, community protection from wildland fire, and enhancing wildlife habitat. Interviewees said that treatments often, but not always, were used in alignment with at least one of their intended objectives. For example, on the Bighorn fire, an AA told us a thin and pile operation around the Summerhaven community was designed to be used strategically for backfires, and it was used for this purpose (Author's note: Backfiring is a more aggressive type of burnout that is used to change the fire's direction or rate of speed (NWCG, 1996)). Other treatments were useful in firefighting, although use during incident management was not their primary purpose. For example, on the Windy Fire, one treatment that was widely considered by interviewees to be the most useful in protecting key values at risk from the fire was originally designed to enhance visitor safety from snags. We frequently heard that treatments were considered during firefighting independent of their intended objective. As one Lick Creek Fire interviewee explained, "Whether it was stated in the burn plan that [the purpose of the treatment] was hazard fuel mitigation, I don't know. I never saw the burn plan. But it helped, regardless. What they're doing it for is a moot issue. It's still a benefit on all angles when they treat it."

What are the key factors impacting how fuel treatments are considered and incorporated into firefighting?

Several conditions influenced how fuel treatments were evaluated or integrated during incident response. First, the communication process, specifically how information about existing fuel treatments was shared among responders during the incident, influenced how treatments were considered and ultimately used during firefighting. In every case study, interviewees primarily shared information about fuel treatments and their potential value (e.g., treatment locations, the current state of the treated area, and operational risk considerations) during each team's initial in-briefing, followed by ongoing discussions throughout the duration of the incident. Interviewees assembled fuel information from a variety of sources. Typically, information was gathered from geospatial databases, information packets assembled by the local forest, from reconnaissance, and through discussions with local staff knowledgeable about the treatments' planning, implementation, or monitoring.

Interviewees recommended that strengthening communication among USFS fire and forest managers and potential fire response personnel, such as state and local fire response partners, before fires are burning can support quicker alignment among personnel during incidents, specifically to enhance understanding of local fuel management plans. Interviewees also recommended that forests have readily available treatment information to share with incoming teams, noting that some forests are more prepared than others. In the U.S., fuel treatment accomplishment information is reported and accessible through the Forest Service Activity Tracking System (FACTS). Generally, interviewees in all case studies positively perceived the communication processes for sharing and receiving fuel treatment information. They told us the in-briefing is typically how fuel treatments are initially considered during firefighting. Some interviewees also expressed concern that forests with elevated levels of staff turnover would lose the in-depth, nuanced knowledge about treatments that comes from having been involved in all phases of a project from planning to implementation, to monitoring and maintenance of a project. Almost all interviewees recommended against establishing a formal agency-wide protocol for sharing local fuel information during incidents with a concern of adding additional administrative commitments to their workload. Rather, they encouraged the use of existing decision support tools like PODs and the Wildland Fire Decision Support System (WFDSS) to support ease of communication about treatments between the agency and other response partners.

Interviewees credited effective communication regarding fuel treatments to a combination of key factors including pre-existing relationships, the culture within the Incident Management Teams (IMTs) and local units, and teams' experience with fire behavior in different ecosystems. First, interviewees said having established working relationships among IMTs and within the local unit allowed for some decision-making efficiencies when considering using a treated area. For instance, during the Lick Creek Fire, one IMT member said they received an overview of treatments prior to arriving on the scene from previously established contacts on the Umatilla National Forest, and, as a result, they had more time to consider response options. We also commonly heard that having a workplace culture that encourages collaboration and working across specialties establishes greater trust among personnel, which can support better communication about potentially using treatments. For instance, some interviewees said IMTs bring unique "team personalities", and as such certain teams have a reputation for being more receptive to working collaboratively with the local unit. In other cases, we heard it can be a challenge to openly discuss options for using treated areas if the IMT or forest staff is less approachable. As one interviewee on the Lick Creek Fire explained, "A huge attribute to helping with the success of the fire too is that [IMTs] always knew they could rely on staff from the Umatilla to provide them information... It is who they are, the philosophy of the forest, and the individuals that work here. They have seen multiple large-scale fires on the unit, so they know what to expect, and they know how to engage. It's organic. It's the Umatilla way."

Several interviewees also told us that IMTs' experience levels in the local fuel type impacted how fuel treatments were used in response. These interviewees discussed previous experiences where some incoming teams that were not as familiar with frequent-fire forests tended to be more hesitant when considering applying fire as a response tactic, particularly when using fire to burn off from a treated area. For example, an Incident Commander on the Bighorn Fire said, "We as a team have a lot of experience on large fires having to do some pretty large landscape level burnouts, just to protect communities or values at risk... it's a lot of comfort levels, because it takes the approval from the Agency Administrator, the Incident Commander, and the locals really, that you're working for and trying to protect, to understand your plan, and that you're going to try to implement it if you can."

Finally, we heard that restrictions related to COVID-19 posed new challenges for sharing and receiving information about fuel treatments during our case studies. Traditional means of communicating face-to-face were limited, and there was also a general expectation to immediately suppress all fires due to the uncertainty of resources. Interviewees thought that both these factors contributed to some apprehension towards incorporating treated areas into incident response during the 2020 fire season.

In addition to how treatment information was shared during incidents, several treatment characteristics also factored into how treatments were considered for their use during firefighting. When considering using a fuel treatment during a fire, most interviewees said they first considered the treatment's proximity to roads and natural holding features, the time since treatment, and how well the treatment had been maintained since implementation. Interviewees said that treatments located along roads were often preferred because the combination of reduced fuel and a pre-existing fire break can often be used for holding or firing with little improvement during the incident. We heard these areas are generally considered safer and more effective for certain operations because of the combination of reduced fuel and a pre-existing fire break. Most claimed that treatments conducted within the past five years, or those recently maintained, often require fewer resources to prepare the area before its use in firefighting, optimizing the area for use. Table 4 presents direct quotes highlighting the fuel treatment characteristics that most interviewees identified as influential to firefighting considerations.

Although these were the common treatment characteristics interviewees looked at when considering utilizing a fuel treatment in our case studies, interviewees said, in most circumstances, utility depends on external, day-of conditions like weather and fuel conditions, fire behavior, and resource availability. Most interviewees said that in circumstances of extreme weather conditions, or with high-intensity fires, it is challenging to rely on treated areas for suppression. We also commonly heard that if there is limited staffing, like hotshot crews, or equipment available to prepare a site, and based on the speed at which a given fire is advancing, a fuel treatment might not be a viable option to prepare or use. Finally, some interviewees pointed out that, during firefighting, they typically consider historical wildland fire scars the same as they would fuel treatments on the landscape, noting

Table 4 Interviewee quotes regarding fuel treatment characteristics that were useful during incident response

"Position on slope is the very first thing... if that work's been done adjacent to a road, then usually that means you can access [the fuel treatment] with equipment and ground-based people. It needs to coincide with a ridge top or a road."—Cub Creek 2 Fire
"Roadside fuel breaks focusing on control features have been shown time and time again, to have been great places to stop fires. That moves into the offensive side of our job, which thankfully we've become more engaged with, [which] is the prescribed fire component, or the proactive work. When we have these roads and ridges prepped and ready, it gives us places to maintain and then start treating at more of a landscape level."—McCash Fire
"Using Summerhaven as an example... if those fuel breaks had been heavily overgrown, [and] had not been maintained for many years... we would not have been able to defend the community."—Bighorn Fire
"I would really look at the slash component. Was it just cut and there's a bunch of slash components still on the ground? So, is it going to be a viable place? It still might be a viable place for us to burn, but it may take more resources for us to build an anchor there."—Trail Creek Fire
"We look at ridges or places that we have been... based on resource time we would choose a place that would need less work [and] provides for higher probability of success during the suppression operations."—McCash Fire

that larger fire scars tend to be more beneficial for supporting incident management.

Discussion

Our interviews across seven case studies of wildfires reflect how wildland fire and forest managers consider and integrate existing fuel treatments into management decisions during wildfire incidents. Although each fire was unique, similar practices, challenges, and opportunities emerged for incorporating fuel treatments into wildfire response. We summarize our key findings regarding our research questions, and then we revisit the literature on decision-making during firefighting to provide further analysis of these findings in a broader context.

Our work is relevant to the ongoing challenge of the difficulty in aligning USFS objectives for land and fire management (Schultz et al. 2019a). This dynamic contributes to the challenge of characterizing and evaluating the effectiveness of fuel treatments. Fuel treatments are often designed to facilitate firefighting and mitigate wildland fire behavior, but they are typically evaluated based on their ability to mitigate fire behavior through direct interaction with fire. This evaluation assumes that treatment interaction with wildfire is a necessary condition to influence outcomes in the incident response context (Thompson et al. 2018, Barnett et al. 2016). Our interviewees highlighted that in addition to moderating fire behavior, fuel treatments are regularly leveraged during firefighting, most commonly for conducting burnouts and to enhance access points for firefighters, creating efficiencies for resource deployment and containment opportunities. Further, our interviewees revealed that fuel treatments can support contingency planning by offering additional options to firefighters. Within the PACE (Primary, Alternate, Contingency, Emergency) incident management model—designed to provide transparency of the primary operational plans and resource allocation if the current mission is compromised—fuel treatments could play a role in expanding contingency options. For example, fuel treatments may provide greater certainty that fire can be held at indirect containment features near the treated area. This aligns with our findings that fuel treatments can provide more alternatives and flexibility in the firefighting decision-making space. Therefore, an opportunity exists to understand fuel treatment effectiveness, both in terms of how treatments facilitate firefighting and how they mitigate fire behavior.

As revealed in our interviews, several social and ecological conditions impact how fuel treatments are considered or used in firefighting, including treatment characteristics (e.g., time since treatment, location) and day-of considerations (e.g., wind speeds). The spatial scale of intended treatment effects also varies widely across treatment objectives and must be considered when designing treatments to maximize benefits. More work is needed to consider whether and how to design and implement treatments that can amplify both localized and landscape-scale treatment needs. The most advantageous fuel treatment location and design is also informed through various strategic frameworks, fire models, and other data sources such as the Potential Operational Delineations framework (Thompson et al. 2016) or Strategically Placed Landscape Area Treatments (Finney 2001). Acknowledging these considerations could improve the design and implementation of forest treatments to support more holistic forest management and better inform forest policy (Hood et al. 2022; Vorster et al. 2023). At the same time, we suggest it might be most realistic and important to clarify and prioritize the objective for which fuel treatments are being designed and then consider whether there might be ways to optimize (but not compromise) their design to meet other relevant objectives. For example, if a treatment is designed for wildlife habitat restoration, but there is an opportunity to place the treatment in a strategic location (such as near roads) without impacting the treatment's ability to achieve its primary objective, then it might also serve to facilitate incident management, thus aligning multiple objectives. In some places, this approach may already be happening. We suggest that looking at objectives more explicitly or possibly in tandem may facilitate a clearer and, in some cases, more integrated fuel treatment strategy. Another alternative would be to move towards prioritizing among these objectives when designing treatments depending upon a treatment's likelihood of success vis-à-vis a particular objective.

One way to advance the evaluation of the treatment effects on multiple objectives would be to revise USFS documentation to capture a range of evaluation measurements. Shifting the agency toward a process that evaluates fuel treatments to include multiple objectives or to clarify how to design fuel treatments informed by multiple objectives would require substantive organizational change. For example, this might look like creating a requirement for responders to document their experiences of using treatments to aid firefighting or assessing managers' ability to design treatments with multiple objectives in mind. This change differs from the existing USFS policy to monitor fuel treatment effects in the FTEM application, where documentation for more detailed information, such as how treatments were incorporated into firefighting decisions, is optional and not well captured (Hood et al. 2022). To help illustrate how this might look in practice, we have provided examples of fuel treatment effectiveness metrics related to firefighting, their definitions, and common measures used to evaluate the impact of treatment (Table 5). We developed this example from treatment utilities that emerged from our results and considerations proposed by Vorster et al. (2023) and Hood et al. (2022). To summarize, treatments are often evaluated for their ability to directly alter fire behavior; however, we found that treatments are also used to support incident management objectives but are not typically recognized or evaluated for achieving this objective. Our findings support recommendations that the consideration of multiple fuel treatment effect metrics, specifically their use to assist firefighting, provides a more holistic view of treatment utility (Hood et al. 2022; Vorster et al. 2023). This approach also has the advantage of capturing fuel treatment utility outside of the treatment footprint, better characterizing treatment use which could inform efforts to understand treatment effectiveness at the landscape level.

Considering that these changes may not be feasible in the immediate future, we provide the following additional recommendations to support the use of fuel treatments during incidents more immediately. These recommendations build off insights from our results which revealed several social dimensions that impacted how fuel treatments are used during incident management including pre-established working relationships, how information about existing fuel treatments is shared among responders during the incident, and workplace culture (e.g., a workplace that fosters robust communication practices). First, one way to support the consideration and use of fuel treatments during incident response is for forest and fire leadership to encourage purposeful pre-fire coordination among responders and non-fire staff members, including state and local fire response partners. This recommendation aligns with existing literature demonstrating that proactively building working relationships in advance of fire season and exposure to forest information before arriving on an incident is a valuable practice for enhancing decision-making efficiencies during wildfires. For example, local managers and IMTs have attributed greater decision-making efficiencies during incidents to the strategic collaborative planning and relationship-building completed during their Potential Wildfire Operational Delineations (PODs) workshops (Caggiano et al. 2021). Our interviewees highlighted that,

Table 5 Examples of forest fuel treatment metrics related to wildfire incident management, their definition, and common measures used to evaluate the impact of treatment

Metric	Definition	Evaluation measurement examples
Wildfire suppression activities	Treatments altered firefighting actions or decisions during wildfire incident	• Use of treatments to improve suitability of features to serve as a control or anchor point, structure protection opportunity, and/or a burnout • Incident safety rates • Use or consideration of treatments during incident strategy development, prioritization, and decision making
Ingress and egress routes	Treatments impacted human movement during wildfire incident	• Adequate evacuation, emergency services, or firefighter access
Contingency activities	Treatments impacted contingency planning or actions during wildfire incident	• Use of treatments within the PACE (Primary Alternate Contingency Emergency) model • Use of treatments to create more viable safety zones • Use or consideration of treatments during incident strategy development and decision making

whether through formal measures like PODs or more informal partnership meetings, building trust and awareness of local political and social dynamics and understanding local fuel plans is important before fire season starts. As shared in our results, in places where state and local fire response partners were engaged with the forests' fuel management strategy and prescribed fire plans, IMTs were more receptive to integrating treatments into response.

Another key element of elevating and supporting the use of fuel treatments for firefighting is for local fuel treatment information to be readily available. Our interviewees stressed that they did not want a formal agency process required to share information among teams (both among local IMTs and from team to team), but rather establishing consistent and direct communication practices specific to each forest's needs should be a standard expectation to help ensure consistent transfer of information. Investments should be made in resources designed to support coordination and greater accessibility to existing treatment information. For example, when PODs are used to design fuel treatments, they serve to bring invaluable information for local managers and incident management members before and throughout the duration of an incident (Buettner et al. 2023). We note that our interviewees also affirmed that incoming teams will always scout the area to see real-time conditions, but having documentation of existing fuel treatments in advance of arriving on-site can add efficiencies to the decision-making process. This also could be emphasized as an expectation within USFS and IMT organizational culture.

One way to strengthen working relationships before the fire season and enhance communication and information transfer among teams during an incident is for the USFS, as an organization and at the forest leadership level, to encourage the integration of decision support tools and resources designed to support coordinated communication. There are several existing tools and practices established for this purpose. For example, the USFS Risk Management Assistance has various tools and products designed to enhance risk-informed wildland fire decision-making (Schultz et al. 2021). The Incident Strategic Alignment Process is another process developed to encourage intentional risk-based decision-making throughout an incident. Finally, to support the integration of fuel treatments to support incident management, our interviewees recommended that the USFS should commit sustained resources to address staffing and equipment limitations to support strategic treatment planning, implementation, and regular maintenance of treatments to create and maintain fuel treatments that can be useful during future incidents. Currently, the budget for treating fuels and the rate of treatment are insufficient relative to the scale of the problem (Valliant and Reinhardt 2017). This recommendation aligns with our findings as our interviewees advocated for long-term investments in staffing and equipment required to implement treatments and conduct regular treatment maintenance.

These recommendations are opportunities to enhance and elevate the use of fuel treatments during incident management. However, more work is needed to understand how to improve USFS monitoring programs to establish systems for elevating, documenting, and rewarding the use of fuel treatments during incident management. This challenge is compounded by the fact that the scale and pace of fuel treatment implementation in the United States do not match the need (Prichard et al. 2021). Prescribed fire treatments, for example, are limited by cost, availability and quality of liability insurance, air quality regulations, equipment availability, personnel capacity, access to training, and the need for ongoing maintenance (Schultz et al. 2019b). Mechanical treatments are constrained by legislation, land designations, operational constraints, funding and contractor capacity, markets, and administrative boundaries (Prichard et al. 2021). Ideally, managers should attempt to meet multiple objectives, balancing fuel reduction benefits with ecological outcomes and habitat conservation, and with potential utility for suppression (Vorster et al. 2023). Fuel treatments are more likely to have benefits that offset treatment costs if they meet multiple different benefits (Hunter and Taylor 2022). The fact of limited resources available to plan for, conduct, and maintain fuel treatments elevates the importance of strategic treatment design and placement to maximize potential benefits.

Our study highlights the importance of wildland fire and forest manager perspectives for understanding how fuel treatments are incorporated into firefighting. However, incident response data is challenging to acquire as wildland fire and forest managers disperse after an incident which constrains data to participant's recollection and accessibility for an interview (Vorster et al. 2023). Further, not all treatment interactions were recorded in FTEM during our sampling period. We also did not cross-check in this study interviewee's perceptions of treatment utility compared to other measurements of fire behavior outcomes or treatments' intended objectives, beyond participant recall, but doing so might yield additional information in future studies. Our study is also limited by our inability to capture perspectives of every desired role in each of our case studies due to people's availability; on one fire, we were unable to talk to Incident Commanders, and on another, we could not connect with a Fire Management Officer.

Despite these missing roles, we believe our findings remain relevant as our findings were consistent across all case studies. During our final interviews, we learned that Long Term Fire Analysts (LTANs) and Fire Behavior Analysts (FBANs) can play central roles in delivering fuel treatment information to IMTs on-site. While we interviewed one LTAN, we likely missed some perspectives from not targeting these roles during recruitment. Future studies can expand our work by focusing on perspectives from fire analysts to understand how they gather and communicate fuel treatment information during incidents.

Conclusions

Our findings demonstrate that fuel treatments provide value to tactical decisions during fire incidents, a typically unrecognized objective of fuel treatments. As we detail more in our review of the literature at the beginning of this paper, fuel treatment effectiveness is typically reported on whether the treated area directly intersected the fire and how fire behavior and impacts were altered as a result. Minimal work has evaluated how treatments are potentially considered and utilized during incident response. Our findings fill this gap by illustrating that fuel treatments are valuable both for altering fire behavior and supporting incident management. We suggest there is an opportunity to understand how treatments affect a broader range of objectives and decisions. At the same time, there may be an opportunity to design treatments to protect ecosystem attributes and make them useful for incident management without compromising their original intent. In this case, a question remains about how or whether to balance and optimize against multiple objectives, and, in turn, how to measure effectiveness.

An emergent finding in our work was the importance of Incident Management Team composition and dynamics on fuel treatment considerations and decision-making during incidents. We recommend future studies observe or study IMTs to understand how team dynamics and experience influence the consideration of fuel treatments and associated decisions during incident response. We also suggest a need to further explore how previous wildland fires are considered and used during incident response. Continued reflection on fuel treatment implementation and use remains necessary for supporting and improving forest management.

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Authors' contributions
Conceptualization, SMG and CAS; investigation and analysis, SMG, CAS, and KMN; writing, all authors, led by SMG; Project Administration and funding acquisition, CAS. All authors read and approved the final manuscript.

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Data availability
Data for this study are confidential and not publicly archived due to data privacy and confidentiality procedures in the Institutional Review Board human subjects research protocol (#1854). Our interview guide is available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
Informed consent was obtained from all subjects involved in the study. The study was conducted in accordance with and approved by the Institutional Review Board of Colorado State University (Protocol #1854).

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All authors whose names appear on the submission approve the version to be published.

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