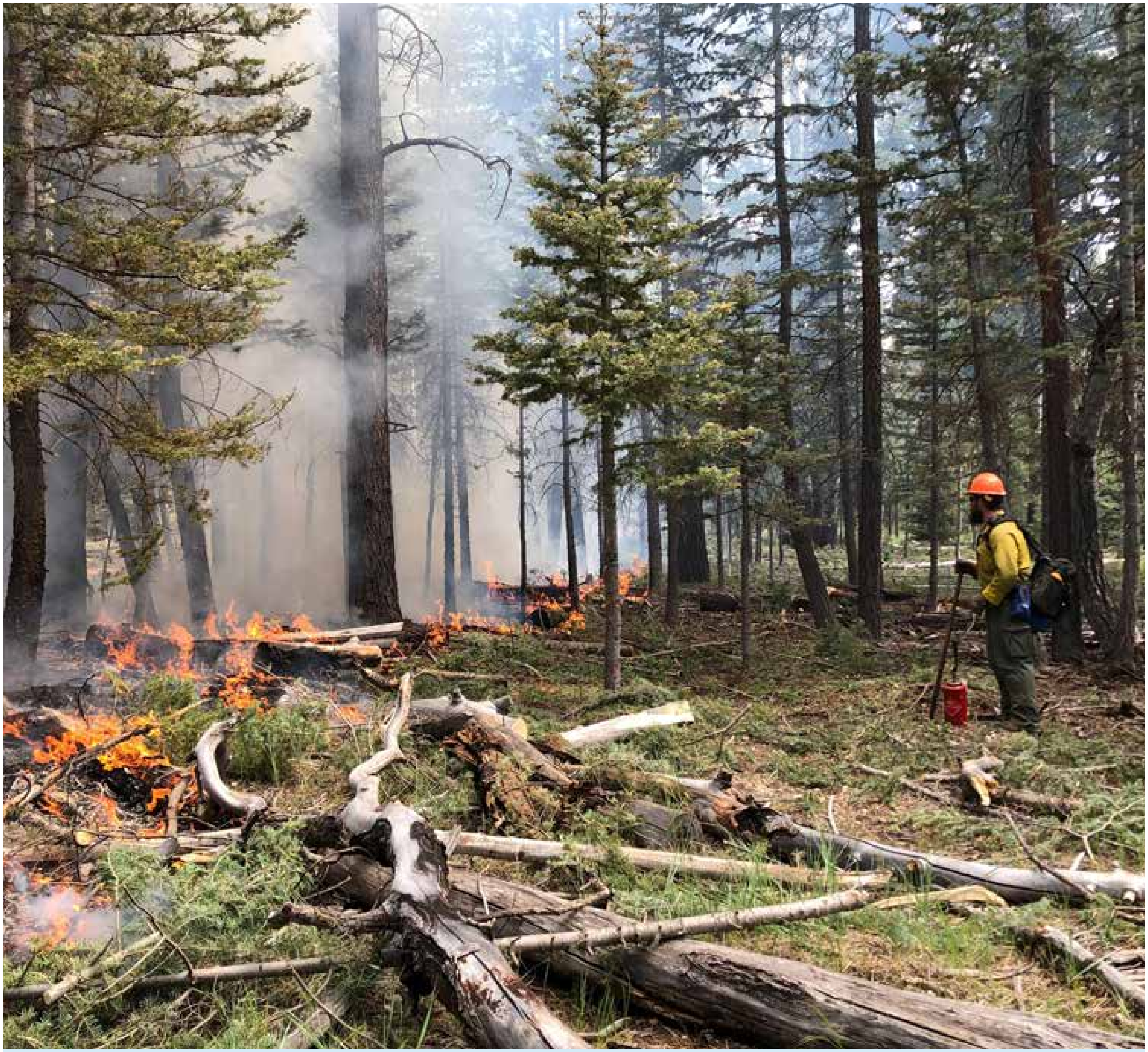

Managed Wildfire: A Research Synthesis and Overview

APRIL 2023

NAU NORTHERN ARIZONA UNIVERSITY
Ecological Restoration Institute

SOUTHWEST FIRE SCIENCE CONSORTIUM

Forest Stewards Guild
putting the forest first

Intermountain West Frequent-fire Forest Restoration

Ecological restoration is a practice that seeks to heal degraded ecosystems by reestablishing native species, structural characteristics, and ecological processes. The Society for Ecological Restoration International defines ecological restoration as "an intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability.…Restoration attempts to return an ecosystem to its historic trajectory" (Society for Ecological Restoration International Science & Policy Working Group 2004).

Most frequent-fire forests throughout the Intermountain West have been degraded during the last 150 years. Many of these forests are now dominated by unnaturally dense thickets of small trees, and lack their once diverse understory of grasses, sedges, and forbs. Forests in this condition are highly susceptible to damaging, stand-replacing fires and increased insect and disease epidemics. Restoration of these forests centers on reintroducing frequent, low-severity surface fires—often after thinning dense stands—and reestablishing productive understory plant communities.

The Ecological Restoration Institute at Northern Arizona University is a pioneer in researching, implementing, and monitoring ecological restoration of frequent-fire forests of the Intermountain West. By allowing natural processes, such as low-severity fire, to resume self-sustaining patterns, we hope to reestablish healthy forests that provide ecosystem services, wildlife habitat, and recreational opportunities.

The Forest Stewards Guild practices and promotes responsible forestry as a means of sustaining the integrity of forest ecosystems and the human communities dependent upon them. The Guild engages in education, training, policy analysis, research, and advocacy to foster excellence in stewardship, support practicing foresters and allied professionals, and engage a broader community in the challenges of forest conservation and management.

The Southwest Fire Science Consortium (SWFSC) is a way for managers, scientists, and policy makers to interact and share science. SWFSC's goal is to see the best available science used to make management decisions and scientists working on the questions managers need answered. The SWFSC tries to bring together localized efforts to develop scientific information and to disseminate that to practitioners on the ground through an inclusive and open process.

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Cover photo: 2019 Castle Fire, Kaibab National Forest. *Photo courtesy of InciWeb*

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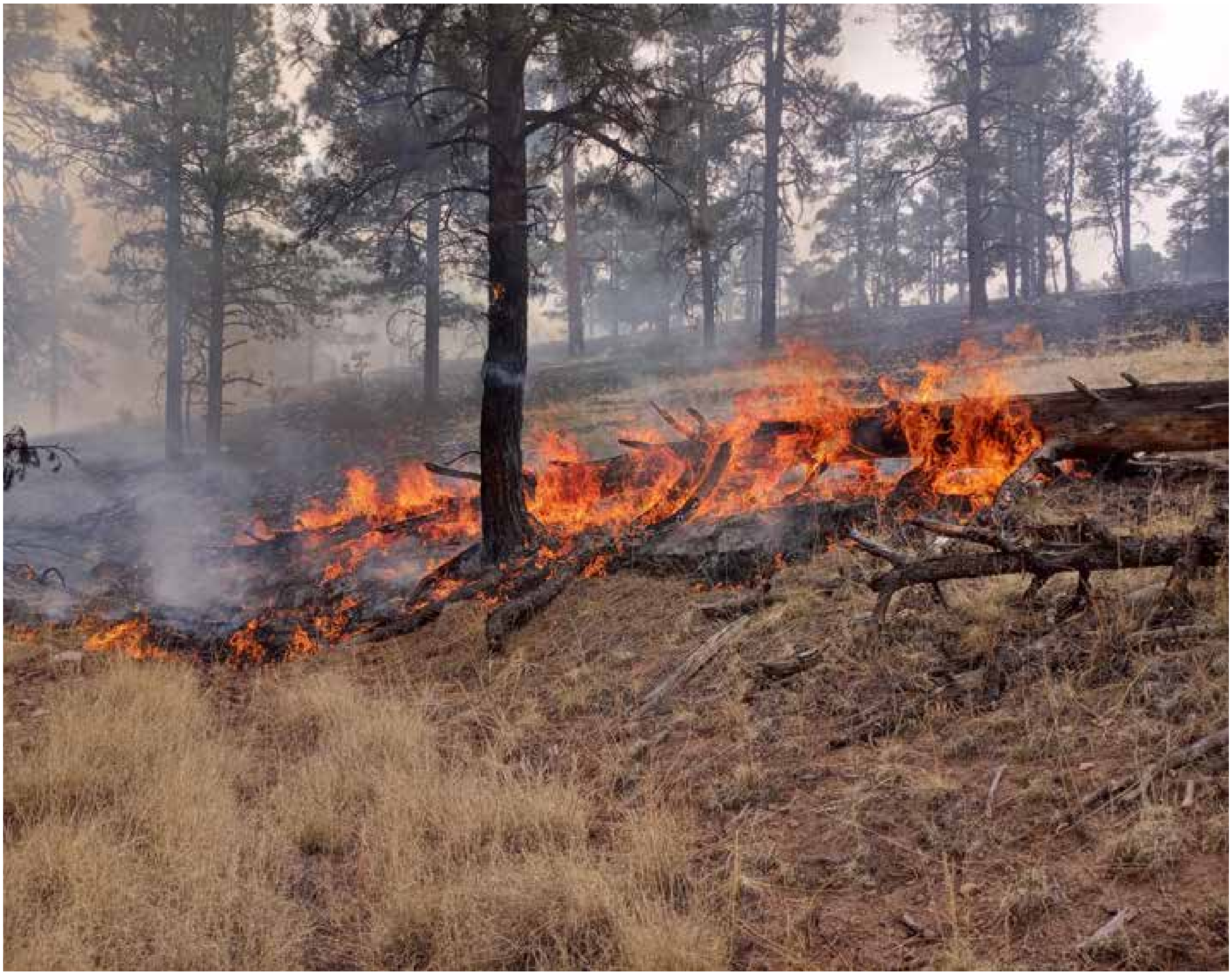


2021 Doagy Fire, Gila National Forest. *Photo courtesy of InciWeb*

Executive Summary

All wildfires in the United States are managed, but the strategies used to manage them vary by region and season. "Managed wildfire" is a response strategy to naturally ignited wildfires; it does not prioritize full suppression and allows the fire to fulfill its natural role on the landscape, meeting objectives such as firefighter safety, resource benefit, and community protection. This wildfire management strategy can be effective for reducing tree densities, landscape homogeneity, fuel load continuity, and future fire behavior, while also working to reintroduce fire to fire-prone ecosystems. Research on managed wildfire has expanded significantly in recent years. This synthesis is designed to distill the current science on managed wildfire to foster a wide discussion of the strategy among managers, practitioners, and the knowledgeable public.

Managed wildfire has been in use since at least the 1910s in the federal land management realm, despite falling in and out of public and political favor over the intervening decades. Managers currently manage wildfires for resource benefit and community safety on hundreds of thousands of acres each year. Accurately tracking the use of managed wildfire is fraught and likely underestimated because of reporting and naming inconsistencies. Overall, the absence of a consistent title for the strategy invites internal and external confusion, disincentivizes use of the strategy, and makes assessment, monitoring, research, and communication difficult.

Based on the existing literature, significant policy, regulatory, physical, and social barriers impede the use of managed wildfire. For fire managers, use of this strategy requires a complex decision-making process that includes consideration of institutional influences, operational considerations, fire outcomes, fire environment, perceived risk, and sociopolitical context. Some new treatment and response planning tools, such as Potential Operational Delineations (PODs), may facilitate greater use by easing some of these barriers and concerns. The scale of the wildfire challenge across the country suggests that, in the future, managed wildfire will play an essential role in managing fuels, reducing burn severity, enhancing suppression effectiveness, fostering forest resilience, and improving human's ability to coexist with fire.

Introduction

In fire-adapted forests across the western United States, unnatural fuel-loading resulting from decades of wildfire suppression, extreme drought, and climate-change-driven aridification have created conditions that leave forests more vulnerable to insects, pests, disease, and high-severity wildfires (North et al. 2021). The frequency, size, and severity of wildfires have increased significantly in recent decades (Abatzoglou et al. 2021, Singleton et al. 2021). Post-fire impacts such as flooding and debris flows can damage ecosystems, infrastructure, and communities more than the flames (Fraser et al. 2022). In response, land managers are faced with the challenge of restoring forest resilience and preventing large high-severity wildfires (North et al. 2021, Schoennagel et al. 2017) while balancing social and environmental constraints (Sample et al. 2022).

Tools for reducing the threat of wildfires to communities and ecosystems include fostering fire-adapted communities, education and implementation programs, fuel reduction thinning, and reintroduction of fire. Home mitigation measures can be crucial for reducing loss (Meldrum et al. 2022). Fire-adapted communities are more resilient to wildfire but are most effective when paired with efforts to reduce fire threat in the adjacent wildlands (FAC Net 2022, Toman et al. 2013). The scientific consensus highlights the ability of fuel reduction treatments to change fire behavior (Prichard et al. 2021), with numerous studies documenting the efficacy of fuel treatments in a range of conditions (e.g., Kalies and Yocom Kent 2016). Mechanical or hand thinning, while efficacious, is expensive and often limited by physical or administrative constraints (Hartsough et al. 2008, North et al. 2015). Treatments that combine thinning and surface fuel reduction, which in most cases means the use of fire, are the most effective at moderating wildfire behavior (Cansler et al. 2022, Evans et al. 2011, Kalies and Yocom Kent 2016, Martinson and Omi 2013). Prescribed fire is usually the most cost-effective tool to reduce surface fuels, particularly over large areas (Cleaves et al. 2000, Hartsough et al. 2008). Prescribed fire, especially multiple burns over an interval of years, can reduce the threat of high-severity wildfire (Collins and Stephens 2007, Stephens and Moghaddas 2005) and drought-driven mortality (van Mantgem et al. 2021).

The need for reintroduction of fire to fire-adapted landscapes is widely recognized. *The Guidance for Implementation of Federal Wildland Fire Management Policy* asserts that "fire, as a critical natural process, will be integrated into land and resource management plans and activities on a landscape scale, and across agency boundaries" (USDA and USDOI 2009). Prescribed fire has been used as a management tool by the indigenous peoples who first populated North America since time immemorial, early European settlers since the 19th century, and private landowners and government land managers since the 1930s (Fillmore et al. 2021, Roos et al. 2022). Despite its widespread use, prescribed burning is subject to a range of social (smoke, proximity to homes, public concern) and operational (accessibility, slope, environmental conditions) considerations that limit the scope and range of its application (Quinn-Davidson and Varner 2011, Ryan et al. 2013). Another tool to reintroduce fire and increase forest resilience that is gaining renewed interest is the management of naturally ignited wildfire for objectives such as resource benefit and community safety.

While prescribed fire involves deliberately igniting fire to burn in a planned and controlled manner to achieve land management objectives, managed wildfire entails managing wildfire for an objective "other than full suppression." Rather than suppress select wildfires as soon as possible, at the smallest possible size, practitioners manage them in a way that achieves ecologically beneficial outcomes and enhances community safety. This approach is difficult because of potential escape, perceived risk, sociopolitical hinderances, operational limitations, and problematic fire environments. This report, which focuses on the realm of federal wildfire response, reviews the current research on these "managed wildfires." The aim of this synthesis is to provide a scientific foundation for continuing discussion of managed wildfires among managers, practitioners, policy makers, the wider community, and across research disciplines. Research on the topic has expanded significantly in recent years without an accessible synthesis that spans scientific disciplines. The following sections summarize the history, terms used for the approach, ecological effects, policy context, and potential future of managed wildfire.

History of Wildland Fire Response and Nomenclature

One of the difficulties in studying or discussing the management of wildfires for ecological benefit and resource objectives is the absence of a common name. The concept has had many titles over the past century, all of which reference the basic intention to react to wildfire ignitions in a way which does not prioritize full suppression and potentially allows for the fire to fulfill its natural role on the landscape. This report uses the phrase "managed wildfire," but fire management history includes a multitude of names for the approach.

Homo sapiens, and before them *Homo erectus*, have been using fire for more than 400,000 years (Anderson 2006). Indigenous peoples across the continent have been using fire since at least 12,550 BCE for a range of objectives such as hunting, crop management, increased plant yield, pest management, fire hazard reduction, and warfare (Allen 2002, Cooper 1960, Roos et al. 2022, Stewart et al. 2002) as well as managing fuels around communities (Roos et al. 2021). By the 1890s, European settlement resulted in an emphasis on suppression of wildfires (Fowler and Konopik 2007). One of central missions of the US Department of Agriculture (USDA) Forest Service when it was established in 1905 was fire suppression. Over the next century, full suppression became the preeminent response to wildfire. However, there have been efforts to use strategies other than full suppression over much of that time (van Wagtendonk 2007).

From 1916 to 1919, California implemented and dissolved a program based on the fiscal burden of full suppression to allow low-intensity wildfires to spread in remote areas unless they threatened high-value timber or improvements. In the 1960s, the National Park Service implemented programs to take advantage of wildfires. Saguaro National Park named their approach "natural prescribed fire" while Yosemite National Park called their program "natural fire management" (van Wagtendonk 2007). The Forest Service followed suite in 1972 with the experimental White Cap Fire Management Area, recognizing "fire as an element of wilderness environments and the need for a more natural incidence of fire" (Beckman 2007). The 1995 *Federal Wildland Fire Management Policy and Program Review* gave the Forest Service definition of "prescribed natural fire" as "allow(ing) lightning-caused fires to play, as nearly as possible, their natural ecological role in Wilderness." This report recommended that "planning should consider all wildland fires, regardless of ignition source, as opportunities to meet management objectives" (Philpot et al., 1995). The policy change in 1995 gave rise to the phrase "wildland fire use for resource benefit," or more simply "wildland fire use" (Miller 2003). Managers and researchers have used other terms such as "let burn," "natural fire," "wilderness fire," "ecological fire use," "appropriate management response," and "wildland fire use" (Fillmore et al. 2021). It is worth highlighting that during this period much of the focus for managed wildfire was on wilderness areas where other management options are limited (Hunter et al. 2014, Miller and Aplet 2016) and that these policies produced public outcry against public agencies, which were seen as having a "scorched earth" policy (van Wagtendonk 2007).

By 2008, the National Wildfire Coordinating Group (NWCG) was referring to "wildfires managed for resource benefit objectives" (NWCG 2008). This was shortened to "resource objective wildfire" in many publications (Meyer 2015, Scott et al. 2012). Similarly, the 2014 National Cohesive Wildland Fire Management Strategy referred to this strategy as "managing wildfire for resource objectives" and alternately "wildfire for resource benefit" (USDA and USDOI 2014). In 2018, the national Incident Management Situation Report (IMSR) identified the percentage of each wildfire that was managed with a monitor, confine, point protection, or suppression strategy. In doing so, IMSR referred to managing wildfires for objectives "other than full suppression" (Fillmore et al. 2021).

Difficulties with Names

The challenge of producing a common name for the strategy is condensing a complicated risk-based response into a short useable phrase. Most recently, "managed wildfire" has become a common term for the management of natural ignitions in a way that provides for safety of firefighters, achieves resource objectives, and enhances the resilience of communities. Some tension exists around the use of the term "managed wildfire," as federal agencies are careful to state that all fires are managed, albeit using different response strategies. A 2022 letter from the Chief of the Forest Service emphasized this point:

> "We do not have a 'let it burn' policy. The Forest Service's policy is that every fire receives a strategic, risk-based response, commensurate with the threats and opportunities, and uses the full spectrum of management actions, that consider fire and fuel conditions, weather, values at risk, and resources available and that is in alignment with the applicable Land and Resource Management Plan" (Moore 2022).

2016 Mormon Fire, Coconino National Forest. *Photo courtesy of George Jozens, USDA Forest Service*

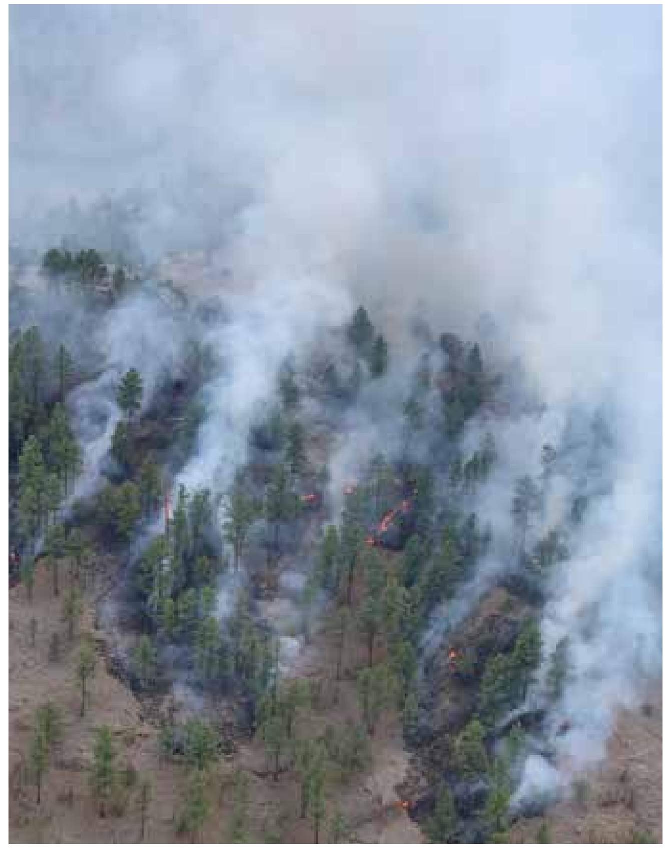
Unfortunately, until the wildfire community settles on a shared lexicon, it will be difficult to track, measure, and understand managed wildfires. Various wildfire incident databases refer to the strategy using different names throughout time, making comparison difficult (Young et al. 2020). Even communication between land managers can become clouded because of differing terminology (Davis et al. 2022). Differentiation is also important because, as the following sections highlight, managed wildfires differ from full suppression wildfires in where, when, and how they burn.

Effects of Managing Wildfire for Resource Benefit

In general, wildfire has a moderating effect on subsequent fires. A study in Washington found that for ten years after wildfire, subsequent fires experienced reduced severity (Cansler et al. 2022). This effect was found to be true for managed wildfire in a recent synthesis of science-based management strategies to foster resilient forests, which concluded "managed wildfires generally burn under more moderate weather conditions and contribute to variable fire effects and surface fuel reduction that can mitigate future wildfire severity" (Prichard et al. 2021).

Severity and Forest Structure

A systematic review of 37 research papers on managed wildfires found they were effective for reducing tree density and future fire behavior (Huffman et al. 2020). The review also found an increase in vegetation heterogeneity and invasive species where fires burned with high severity. An important caveat from the systematic review is that the managed wildfires studied tended not to reduce tree densities enough to return to forests' historical ranges (Huffman et al. 2020). For example, a study of 10 managed wildfires in northern Arizona found 85 percent of the collective burn footprint was classified as unburned/low severity, but areas of moderate burn severity were more likely to help restore forests to their historical range of variability (Huffman et al. 2017). Even repeat entry managed wildfires with predominantly low severity effects in northern Arizona do not appear as effective for returning forests to a more resilient state as a single managed wildfire with moderate severity effects (Huffman et al. 2018). Across the same area, low-severity managed wildfires have not increased landscape heterogeneity enough to replicate historical patterns (Donager et al. 2021). Modeling suggests that moderate-severity managed wildfires would be required to restore historical conditions in dry forests of eastern Oregon (Greenler et al. 2023). Repeat low-severity fires in the Gila National Forest did reduce the probability of future high-severity wildfire (Hunter et al. 2011). A study of 735 wildfires from 1984 to 2017 in Arizona and New Mexico found the size of high-severity patches in managed wildfires tended to be within the historical range of variability for both wet and dry conifer forests (Singleton et al. 2021). These findings align with a study from California that found fire severity patterns for managed wildfires were overwhelmingly within the natural range of variation and greater proportions of moderate severity help forests return to historical conditions (Meyer 2015). An analysis of 1,434 wildfires in the Southwest and California found that nearly 89 percent of managed wildfires and 67 percent of full suppression wildfires burned less than 20 percent of the total area at high severity (Iniguez et al. 2022). Managed wildfires in the Southwest tend to have less high severity than those in California.



2021 Doagy Fire, Gila National Forest. *Photo courtesy of InciWeb*

Other Effects

In addition to positive effects on forest structure, bringing fire back to fire-adapted forests benefits streams and rivers. Fostering a natural fire regime in Yosemite National Park for over 40 years has helped promote a healthy water system and drought-induced tree mortality has declined (Boisramé et al. 2019). The area also has improved landscape and species diversity as a result of the use of managed wildfire (Stephens et al. 2021). The Selway-Bitterroot Wilderness, the Bob Marshall Wilderness Complex, and the Frank Church-River of No Return Wilderness provide long-term, on-the-ground examples of managed wildfire, furthering the goals of fire-safe communities and resilient ecosystems (Berkey et al. 2021). Although managed wildfire is more common in the western US, a study from Arkansas shows the potential for using the approach to move forest structure and composition toward an open woodland condition in the Ouachita Mountains (McDaniel et al. 2020).

Risks

Increased management of wildfire for resource objectives will enlarge the area burned each year in the near term (Barros et al. 2018, Young et al. 2022). This growth could be seen as valuable given the fire deficit in most fire-adapted forests, but an increase in burned area is not universally viewed as a benefit. A simulation study of the Cascade Mountains of Oregon indicated managed wildfire "can improve forest resilience and contribute to restoration efforts in fire-adapted forests," but potential tradeoffs include increased smoke and declines in certain types of wildlife habitat (e.g., decadent mixed conifer) (Barros et al. 2018).

Managed wildfire is not without risk, predominantly the risk of a wildfire spreading beyond the planned area and threatening communities (Ager et al. 2017). A simulation of the Selway-Bitterroot Wilderness estimated that wildfires that ignited in the interior had a less than one percent chance of burning outside of the wilderness area (Barnett et al. 2016). There are examples of managed wildfires escaping planned boundaries (e.g., 2009 Mill Flat Fire in Utah, 2017 Bonita Fire in New Mexico (Davis et al. 2022), and the 2006 Warm Fire in Arizona (Timberlake et al. 2020)), but the difficulty in identifying and tracking managed wildfires means an exhaustive list of escapes is not available.

Current Use and Policy Context

Managed wildfires are a commonplace occurrence on the landscape. Over 900 large wildfires in the western US were managed across 3.9 million acres using strategies other than full suppression between 2002 and 2016 (Young et al. 2020). In 2009, managers used natural ignitions to return fire to over 250,000 acres in the Southwest region alone (Young et al. 2020). The combined footprint of managed wildfires in the western contiguous United States covers an average of 268,000 acres annually compared to 2.9 million acres of wildfires managed with a full suppression strategy (Young et al. 2020).

A strategy other than full suppression is chosen more often later in the season, usually starting after dangerous wildfires have been controlled and when managers know that a season-ending weather event is likely in the next six to eight weeks. Because managed wildfires generally burn under cool, moist, and moderate weather conditions, they tend to exhibit low to moderate fire severity (Meyer 2015). Managers are, understandably, more willing to manage wildfires for resource and community benefit when weather conditions are conducive to control and lower intensity (Young et al. 2020). A sample of managed wildfires in Arizona and New Mexico found they tended to occur when relative humidity was high, wind speeds were low, and fine fuel moistures were high (Huffman et al. 2017).

There are important regional differences in how and where wildfires are managed for resource and community benefit. For example, managed wildfires in California tend to be closer to wilderness and to have a larger percentage of high severity compared to managed wildfires in the Southwest (Iniguez et al. 2022). After 2009, the number of managed wildfires increased in the Inland Empire, Rocky Mountains, and Southwest regions while other regions, such as California, continued to utilize suppression strategies for most large fires (Young et al. 2020). Managed wildfires are less likely than full suppression wildfires to involve multiple responding agencies and entities (Iniguez et al. 2022). Detailed case studies of managed wildfire found opportunities and obstacles to the strategy were "strongly shaped by local interagency and cross-jurisdictional contexts" (Davis et al. 2022).

Policy and Planning

In addition to temporal and geographic differences, policy is an important factor in determining if wildfires are managed with strategies other than full suppression (Franz et al. in preparation). Current federal wildland fire management policy highlights the myriad factors that influence the decision on how to react to wildfires:

> "Response to wildland fires is based on ecological, social, and legal consequences of the fire. The circumstances under which a fire occurs, and the likely consequences on firefighter and public safety and welfare, natural and cultural resources, and values to be protected, dictate the appropriate response to the fire" (USDA and USDOI 2009).

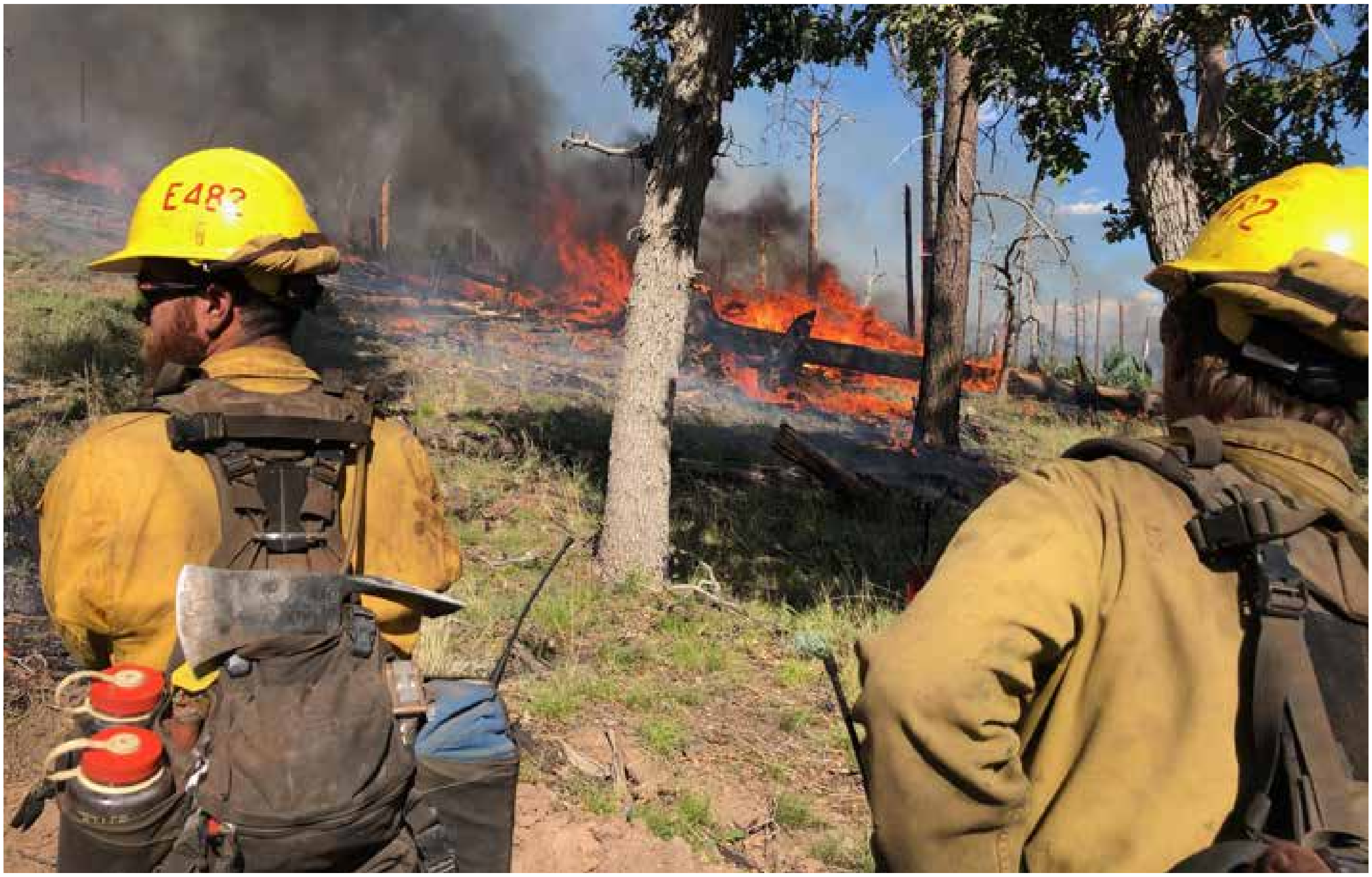
Current policy makes available a full range of wildland fire response strategies to meet management objectives, including containing, confining, or suppressing the wildfire (USDA and USDOI 2009).

Federal Policy

The 2009 federal interagency policy guidance allows federal land agencies to choose to implement multiple fire response strategies on a single wildfire, meaning that they can simultaneously suppress one portion of the fire while managing another for resource benefit (Iniguez et al. 2022, USDA and USDOI 2009). This provides managers the option to use the most appropriate strategy for a particular area based on risk assessments. The 2009 federal policy guidance gave incident commanders greater leniency in managing a single ignition, leading to as much as a 73 percent increase in the number of managed wildfires over pre-2009 figures (Young et al. 2020). Even after policy changed to expand managers' options, managed wildfires still tend to be located closer to wilderness areas and farther from the WUI (Iniguez et al. 2022).

Forest Plans

Fire management still occurs within the framework of forest plans developed in compliance with the National Environmental Policy Act. Creating a forest plan can take years owing to the requirements for in-depth analysis and public input. This delay can result in outdated forest plans, which may not include the option for some resource management tools such as managed wildfire (Schultz et al. 2019, Steelman and McCaffrey 2011). For example, the Kaibab National Forest to was able to manage wildfires like the 2017 Boundary Fire thanks to justification provided in a new forest management plan (Timberlake et al. 2020).



2019 Saber Fire, Coconino National Forest. *Photo courtesy of InciWeb*

Local Influences

Agency directives and culture also influence management decisions. In 2012, a deputy chief at the Forest Service issued a directive that required high-level approval to manage wildfires for resource benefit (Hubbard 2012). This directive appears to have reduced the number of managed wildfires in 2012 and 2013 (Young et al. 2020). A similar directive in 2020 calling for the agency's "predominant strategy being rapid containment" because of the health risk posed by the COVID-19 pandemic appears to have reduced the number of managed wildfires in the Southwest (Christiansen 2020, Lynch and Evans 2021). Again in 2021, the Chief of the Forest Service stated that "At this time … managing fires for resource benefit is a strategy we will not use" (Moore 2021). This directive was viewed as a setback by managers who had been managing wildfires for resource and community benefit (Davis et al. 2022). In California, Title 17 of the Code of Regulations (air quality) requires "registration" of, smoke management plans for, and potentially elicits fees for the smoke from wildfires managed for resource benefits (DODSR 2001). Managers may be using strategies that may not appear to be traditional "full suppression" but are still labeled "full suppression" in part to help navigate the complex intra-agency and local impediments to utilization of this strategy (Davis et al. 2022). Agency directives and culture are important institutional influences on the managed wildfire decision-making process and are woven into many other challenges to using wildfire for resource and community benefit.

Challenges to Implementing a Managed Wildfire Strategy

A review of managed wildfire literature produced a fire management decision-making framework that groups factors into six groups: institutional influences, operational considerations, fire outcomes, fire environment, perceived risk, and sociopolitical context (Fillmore et al. 2021). Based on this review, the largest impediments to using managed wildfire are operational concerns (on-the-ground considerations), risk aversion (fear of potential consequences), and the complexity of the decision-making process itself. In contrast, an individual decision-maker's personal or professional desire to manage wildfire for resource and community benefit was often the main driver for use of the strategy (Fillmore et al. 2021). This highlights managers' and decision makers' understanding of fire's positive value and effectiveness in increasing forest resilience and community safety.

Operational Concerns

Operational considerations that limit managed wildfire include the dangerous accumulation of fuels in many forest stands, the landscape continuity of high fuel loading, location slope and aspect, and more (Young et al. 2020). Climate-change-driven warming and drying trends and ensuing drought conditions increase potential severity of fire behavior, adding to the barriers to managed wildfire (Davis et al. 2022). The same high fuel loads, landscape continuity, and drought conditions that create barriers to managed wildfire create the conditions for wildfire seasons that are longer and more intense. Fire management resources may be increasingly limited for managed wildfires because more large, high-severity wildfires that require full suppression are burning on the landscape simultaneously (Williamson 2007, Young et al. 2020).

Communication and Public Support

Effective community outreach and engagement around forest management projects such as prescribed fire is vital "to address possible barriers to implementation related to a lack of social acceptance" (Novak et al. 2022). Likewise, public support is a key factor for the successful use of managed wildfire, particularly in forested landscapes closer to communities. For prescribed fire, fostering understanding of the purpose and intended benefits helps build public approval (McCaffrey 2006). One fire manager captured this sentiment, saying "if we didn't have that public support, and you have a bad day, you evacuate town, you'll never use fire again in your neighborhood" (Timberlake et al. 2020). As the wildland-urban interface expands and more homes are built in areas at risk of wildfire, the potential for public support to facilitate or limit managed wildfire will also increase.

Managed wildfire lacks some of the prescriptive and administrative controls of prescribed fire even though it creates the same strategic outcome, a discrepancy that leads to distrust or hesitancy among some fire managers and members of the public (Fillmore et al. 2021). While there is no policy dictum to use this strategy only under moderate weather conditions, that is the logical outcome based on risk management and the requirement that "response to wildland fires is based on ecological, social and legal consequences of the fire" (USDA and USDOI 2009). Various national forests have interpreted this guidance to mean that managed wildfire decisions will consider effects on vegetation mortality, the public, and other values based on actual and predicted fire weather and fire behavior modeling. The Wildland Fire Decision Support System (WFDSS) can be and is used to forecast the conditions where the use of managed wildfire could achieve resource objectives (Fillmore et al. 2023).

Risk and perception of risk are key obstacles to managing wildfires for resource and community benefit. Landowners, management agencies, and elected officials who use managed wildfire face, or perceive themselves to face, heightened personal and organizational risk in the short term and receive little direct benefit from the long-term risk reduction managed wildfires can provide (Dunn et al. 2019). Because a full suppression strategy is used with most wildfires, there is also a status quo bias and cultural tendency in the Forest Service against managed wildfire (Wilson et al. 2011).

Drivers of Managed Wildfire Use

Managers and decision makers who do take on the risk of managed wildfires often do so because they believe in the strategy's benefits and efficacy (Fillmore et al. 2021). A study of Forest Service district rangers who authorized managed wildfire (referred to as "wildland fire use" at the time) revealed that 91 percent of them did so because of their personal commitment to the strategy (Williamson 2007).

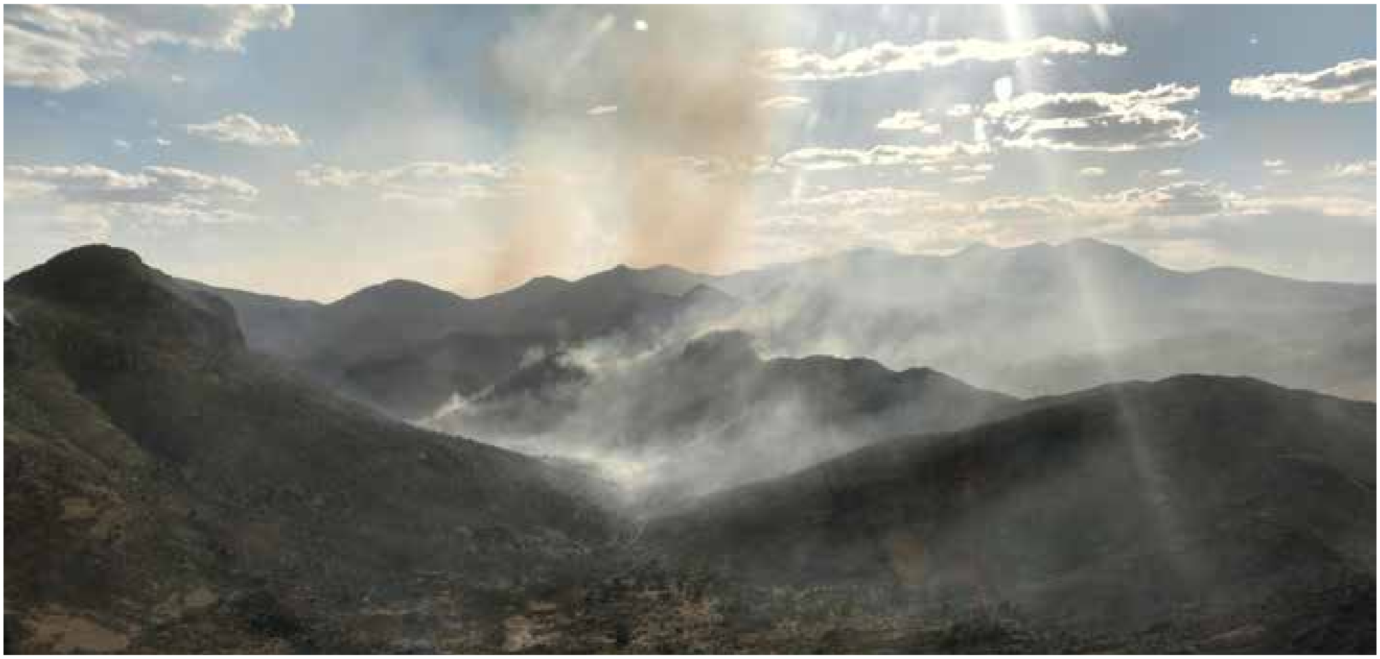
Cost

Cost is unlikely to be a primary driver for the decision to use managed wildfire, but when and where wildfires can be managed for resource and community objectives, they may cost less than full suppression wildfires (Gebert and Black 2012). For example, the Forest Service used the 2011 Long Fire for resource benefit on nearly 500 acres of the El Dorado National Forest for approximately $583 per acre, which is significantly less than the other management options analyzed in the area (Holland et al. 2022). Of the 12 largest wildfires in the Southwest in 2015, the average cost per acre where a suppression strategy was used was $85, while the average cost per acre where wildfire was managed with other strategies was $73 (Evans 2016). A similar comparison in 2016 found $287 per acre for full suppression and $199 per acre for other strategies (Evans 2017). Other studies suggest as much as a 10-fold cost differential between wildfires managed with full suppression versus other strategies (Beasley and Ingalsbee 2021). The lower per acre cost may be because managed wildfires usually burn during weather conditions that are less conducive to rapid fire growth and away from populated areas, therefore requiring fewer resources to manage (Iniguez et al. 2022). Another factor may be the reduced need for aircraft during managed wildfires compared to full suppression wildfires. While strategies other than full suppression may have a lower cost per acre or daily cost, total expenses may be similar to full suppression wildfires because of their longer durations and larger total burn areas (Gebert and Black 2012). Where managed wildfires reduce fuels, they may also reduce the risk and cost of responding to future wildfires that burn through the same area.

Potential Operational Delineations

For use in fire response, the Potential Operational Delineations (PODs) adaptive framework utilizes pre-identified containment features coupled with values at risk to plan for and manage the geographical spread of wildfires. These boundaries are created from fire containment data such as roads, ridgetops, and fuel transitions (Thompson et al. 2020). PODs strive to provide cross-boundary and collaborative utility for planning, communication, coordination, prioritization, incident response strategy development, fuels mitigation, and forest restoration. Teams create PODs based on geospatial decision support models and expert local knowledge, allowing decision makers to develop a range of wildfire response options for an entire landscape prior to the fire season. PODs can aid the development of wildfire response strategies based on values at risk, modeled fire behavior, as well as serving as an educational tool for community outreach. Management strategies can include management of natural ignitions for the most advantageous ecological and community outcomes (Thompson et al. 2022).

Implementation of the PODs methodology and careful preplanning allowed for the successful management of the naturally ignited 2017 Pinal Fire for resource benefit by the



2018 OK Bar Fire, New Mexico. *Photo courtesy of InciWeb*

Forest Service (O'Connor and Calkin 2019). Teams elected to use the strategy of backing surface fire to control wildfire growth, consume abundant downed woody fuels, reduce the number of seedlings and saplings, remove fuel jackpots, and restore fire resilience to the ecosystem. Another spatial planning tool that may aid in reducing the logistical barriers to use of managed wildfire is Potential Control Locations (PCLs), or identification of areas where large fires have historically tended to stop or lull due to topographic features such as lakes, ridges, and rivers (Stratton 2020). Both tools may be used together for optimal planning.

The Future of Managed Wildfire

Pyrosilviculture, or the use of prescribed fire to meet management objectives through fire alone or by altering silvicultural treatments to optimize the incorporation of prescribed fire in the future (York et al. 2021), has gained attention as a tool to increase the pace and scale of forest restoration through reduced stand density in fire-adapted landscapes. North and colleagues, as well as other researchers in the western US, have expanded this approach to recommend using pyrosilviculture to maintain wildfire-treated areas (those burned at low to moderate severity) and to identify managed wildfire zones where initial treatments would be achieved using naturally occurring fire (North et al. 2021).

Research comprehensively suggests that any long-term solution to the tremendous wildfire challenge facing communities and land managers across the western US will involve managed wildfire. Managing natural ignitions for resource and community benefit during moderate weather conditions offers hope for limiting future wildfire spread, reducing burn severity, and enhancing suppression effectiveness (Thompson et al. 2018). A model of forest treatments and management in northern Arizona found that including managed wildfire reduced the projected proportion of high-severity impacts even though the total area burned was projected to increase (Young et al. 2022).

Managed wildfire must also be part of climate change planning and solutions (Sample et al. 2022). A simulation for Lake Tahoe, California that incorporated the effects of a warming and drying climate found that the most effective risk reduction approach included selective use of managed wildfire (Evans et al. 2022). Based on the ecological studies described above, managed wildfires may have to be administered to burn a greater proportion of areas at moderate severity to build forest resilience.

On average, less than 0.5 percent of wildland fire ignitions have been allowed to burn as managed wildfires (North et al. 2015). An increase in the frequency and severity of managed wildfires will require careful risk management such as use of the PODs adaptive framework and clear communication with the public. However, these challenges should be seen not as barriers but as logical and necessary next steps to increase utilization and facilitation of a restorative and cost-efficient forest management tool.

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