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ORIGINAL ARTICLE

Preventing Human-Caused Wildfire Ignitions on Public Lands: A Review of Best Practices

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Abstract

Effective interventions to prevent human-caused ignitions on public lands play a critical role in social and ecological adaption to wildfire. While wildfire prevention spending generates a high return on investment, funding and capacity to support such programing within federal, state, and local land and fire management agencies remains limited. One avenue for ensuring that available funding and staffing for prevention is used to strategically maximize impact is the documentation of best practices, grounded in empirical data, that can provide indicators for effective intervention with public land users. This review informs prevention decision-making by highlighting current best practices categorized under the four key approaches to fire prevention–education, enforcement, engineering, and administration–while simultaneously revealing themes and gaps that merit further attention. We focus on interventions that can reduce accidental or negligent ignitions within the purview of land management and fire prevention professionals. We conclude with a call to modernize the field of wildfire prevention social science that promotes the diversification of study locations, design, and prevention techniques studied. Improved research and documentation surrounding the outcomes of individual or combinations of strategies and the user groups they target can help transition anecdotal assessments of prevention effectiveness into empirically informed decision-making that supports more strategic administration.

Keywords Wildfire prevention · Human-caused ignitions · Education · Enforcement · Engineering · Wildfire risk reduction

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Introduction

Effective implementation of interventions to reduce human-caused wildfire ignition is critical as fire occurrence increases across the US, placing communities and the landscapes that support them at risk (Balch et al. 2017; Nagy et al. 2018; Mietkiewicz et al. 2020). Interventions designed to mediate accidental and negligent behaviors that produce ignitions like abandoned campfires or dragging chains often target public land users and the risks they introduce (Narayanaraj and Wimberly 2012; Abt et al. 2015; Ganteaume and Syphard 2018). The prevention risks that public land users introduce vary depending on their backgrounds, recreation preferences, knowledge of wildfire, and support for prevention activities, indicating the need for a suite of prevention activities implemented in combination to minimize unwanted ignitions (Chandler and Davis 1960; Reilley et al. 2023). Many federal and state land management agencies have staff positions focused partially or exclusively on fire prevention to plan and implement localized, proactive interventions to reduce human-caused wildfire ignition risk. Prevention staff must identify the conditions, techniques, and delivery methods that produce impactful prevention on public lands, particularly in heavily visited areas where ignitions are more likely. However, programmatic constraints such as limited budgets and understaffing necessitate strategic spatial and temporal implementation of prevention actions to maximize intervention impact with the limited resources available (Prestemon et al. 2010; Kohler and Evans 2021). This review aids those responsible for wildfire prevention by summarizing best practices with a focus on key considerations for efficient implementation of each strategy.

Understandings of what wildfire prevention entails have evolved over the course of several decades of practice and research, with many efforts seeking to better define the broad suite of available prevention interventions by categorizing them. One of the earliest efforts to conceptualize prevention was the introduction of the "three Es" – (1) engineering, which includes structural modifications like campfire rings, (2) enforcement, including efforts such as fines, forest closures, or campfire bans, and (3) education, ranging from local efforts like signage and fliers to nationwide campaigns such as Smokey Bear – as a way to classify interventions, originally applied to wildland fire contexts by Riebold (1957). This conceptualization has since expanded to become the "three Es and A," in which the A represents administration across these efforts (together referred to as the wildfire prevention triangle, Fig. 1) (NWCG 2021). More comprehensive interpretations of these categorizations include actions such as home hardening and fuels treatments, while more narrow interpretations prioritize education or outreach-focused initiatives (Wetherill 1980; Hesseln 2018). A vast majority of wildfire social science research related to prevention conducted by land management agencies focuses on education; far less is known about how the public responds to engineering and enforcement-focused interventions, or the role of administration in amplifying or restricting prevention efforts.

Determining the effectiveness of wildfire prevention efforts has long been a goal of managers and administrators tasked with the oversight of programs at the

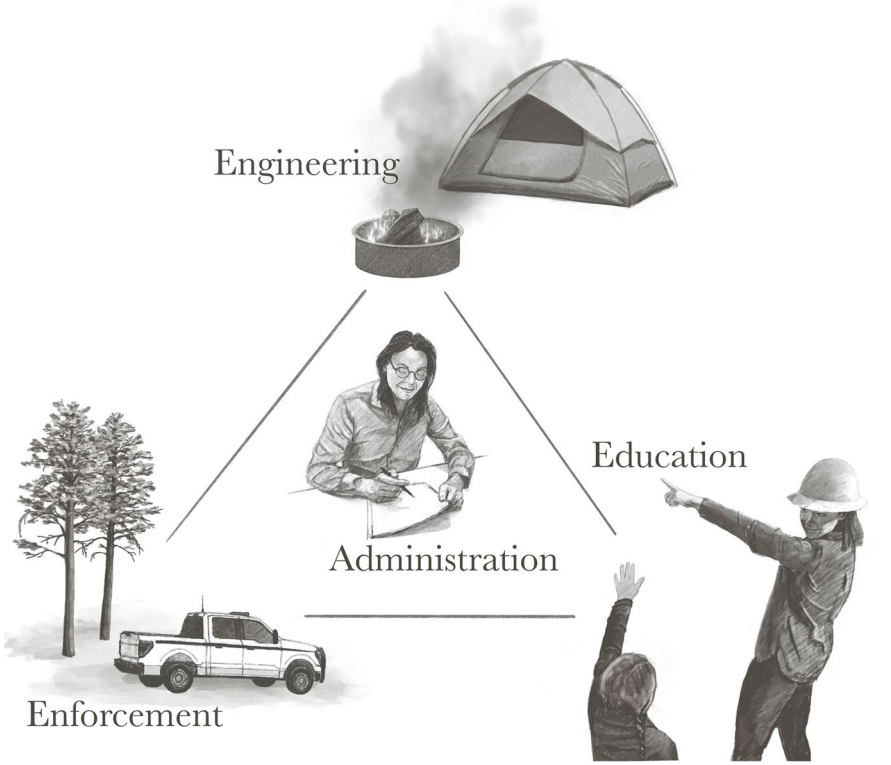

Fig. 1 The fire prevention triangle, adapted from Riebold (1957) and NWCG (2021). Illustrated by Kara Skye Gibson

local, state, and federal levels. However, systematic documentation of relevant data is scarce, and methods for determining effectiveness are rarely agreed upon (Thomas and Butry 2011). In the absence of a universal approach for determining prevention success, economic analyses often act as a proxy. A study conducted in Florida indicated that every dollar spent on wildfire prevention prevents $35 in damage, demonstrating that interventions organized by land management agencies and relevant partners are valuable investments in current efforts to improve social and ecological wildfire adaptation (Prestemon et al. 2010). Despite the growing need for prevention practices, most agency-driven wildfire management efforts focus on suppression and mitigation rather than prevention explicitly, in part because of difficulty documenting cost avoidance generated by prevention efforts (Hesseln 2018). One avenue for ensuring the effective use of available funding and staffing for prevention is the documentation of best practices, grounded in empirical data, that provides indicators for impactful intervention with public land users. To date, best practices across the "three Es and A" have not been collectively documented, but such an effort could streamline prevention planning and decision-making by identifying suitable tools and approaches.

This article provides an overview of intervention strategies currently used to reduce human-caused ignition risk on public lands in the United States and documents empirically proven best practices for their use. We conducted a comprehensive literature review to identify best practices emerging from peer-reviewed studies over time, organizing findings using the wildfire prevention triangle to support streamlined integration of recommendations into existing strategies. We note that much of the available research on this topic is outdated, driven by both a lack of investment in prevention science, the recent incorporation of social media and other modern techniques into prevention programming, and recent shifts in populations accessing public lands. While some overarching efforts to document the state of prevention exist (e.g., Hesseln 2018), we prioritize efforts on public lands (rather than private lands) that can support managers across local, state, and federal entities. Given that the causes of human-caused wildfires are expansive (e.g., railroad activity, agricultural burning, waste management) and many are products of systemic issues that cannot be addressed by prevention alone (e.g., arson, mental illness, aging power infrastructure), our focus here is on interventions that can reduce accidental or negligent human-caused ignitions to ensure that recommendations are within the purview of land management and fire prevention professionals. From 2013–2023, an annual average of 88% of wildfires were caused by humans, of which an estimated 80% are caused by negligence or accident (NIFC n.d.). Documenting progress and opportunities surrounding effective fire prevention programming is essential for generating new approaches and strategies, particularly as the social and ecological conditions surrounding public land use and recreation continue to evolve (Rice et al. 2020; Blahna et al. 2020).

Approach

The National Wildfire Coordinating Group's (NWCG) national wildfire prevention strategy details examples of prevention activities included in the fire prevention triangle (NWCG 2021). We shortlisted these activities to those pertinent to public land use and recreation with a focus on interventions that could address accidental or negligent ignitions, developing a list of keywords associated with each activity. We then conducted a comprehensive review of the literature using both these keywords and more generic prevention terminology to identify existing literature on wildfire prevention relative to public lands in the US (Templier and Paré 2015). Search strings typically began with some combination of "wildfire," "wildland fire," or "forest fire" paired with "prevention," "education," "enforcement," "engineering," or "administration." These were accompanied by various combinations of NWCG-identified keywords such as "campfire ban," "public service announcement," or "signage" among other more targeted terminology. Initial searches were conducted in Web of Science, Treesearch, CAB abstracts, and Google Scholar in January 2024. This was followed by identical searches at key journals such as the International Journal of Wildland Fire, the Journal of Outdoor Recreation and Tourism, and the Journal of Forestry. Lastly, references cited in each publication were reviewed to identify any additional materials, and specific searches were conducted for works by

prominent authors whose work was repeatedly cited to ensure that the resulting publication database was as comprehensive as possible (Fink 2019). Documents were then screened to ensure that they focused on human elements of wildfire prevention that had value for public lands. Irrelevant items were removed, providing a final database of 90 articles that were published from 1937 onward, almost exclusively presenting research from the United States. We opted to conduct a comprehensive review rather than a systematic review because many older publications are not available online, which would prevent our ability to ensure identification and assessment of all existing literature for the latter approach (Haddaway et al. 2020).

We reviewed shortlisted publications, analyzing and qualitatively coding each article for best practices related to prevention activities (Littell et al. 2008; Fink 2019). Coding was conducted by hand in two rounds: descriptive codes that sought to identify the contents and coverage of each publication, followed by thematic coding to identify commonalities in findings across all publications (Saldaña 2013). Intercoder reliability (the comparison of coding efforts between team members to ensure consistency) was also conducted to promote rigor in our analysis. Finally, each publication was also assigned to one or more elements of the fire prevention triangle to accelerate topical grouping of codes. The resultant findings are structured below around the fire prevention triangle's four categories. Not all interventions fit neatly into these categories; for example, while NWCG considers signage an education intervention, they also require engineering effort to install. As a result, segments of most publications were coded multiple times for different descriptions and themes. In the sections below, we follow NWCG's categorization to align our findings with the most commonly used framework to avoid confusion, but acknowledge that many prevention activities occur across a gradient and cannot always be designated to one single category. Activities that center on biophysical solutions to unwanted wildfires that are often considered prevention engineering strategies, such as fuel treatments or management of home ignition zone vegetation, are not included in this review as an abundance of studies assessing the state of those sub-fields already exists (e.g., Gibbons et al. 2012; Calkin et al. 2014; Kalies et al. 2016; Davis et al. 2024). We conclude each section below with a table of best practices that are identified in the literature or emerge across publications.

Findings

Publications identified for inclusion in this review converge around three overarching themes: (1) public and professional interpretations of what constitutes "prevention" are diverse and often inconsistent, (2) one singular prevention approach alone will not eradicate human-caused wildfires, revealing the importance of place-based modifications to prevention programs and strategies, and (3) prevention efforts must be tailored at the local level to engage specific audiences if they are to be successful. The importance of aligning strategies with local needs is underscored across time and locations, and include cooperative prevention in partnership with community members (Parker and Bailey 1980), messaging that aligns with the interests and values of different audiences and comes from respected or familiar individuals

(Reynolds 1950; Folkman 1965; Griessman 1966; Block et al. 1976; Ryan et al. 1978; Bradshaw 1988; Jacobson et al. 2001), and the need for education programs to incorporate examples and discussion of local ecosystems into education programming (Folkman 1963; Ballard et al. 2012) among other place-based prevention techniques. These existing efforts also identify variations in public knowledge of prevention related to tenure in an area, frequency and type of outdoor recreation, and key demographic considerations such as gender, age, and level of education (Chandler and Davis 1960; Reilley et al. 2023).

Methodologically, studies tended to favor survey techniques. Studies of prevention staff often used phone and mail surveys (e.g., Doolittle 1980; Wetherill 1982), while studies of the public more commonly leveraged intercept surveys (e.g., Folkman 1966c; Devenport and Edgeley 2025), reflecting the importance of in-situ data collection to understand place-based human-landscape interactions that may cause ignitions. Fewer studies presented observational data, focus groups, and interviews, signifying a need for more qualitative research to provide additional depth to understandings of human behavior in ignition contexts. Detail regarding the justification behind study site selection was often missing, particularly in older studies; only a handful discussed why they conducted research in a specific location, typically either because public land users who brought ignition risk with them frequented the area, or because the area had a history of human-caused ignitions (e.g., Chandler and Davis 1960; Folkman 1965; Alló and Loureiro 2020). Also missing from studies assessed in this review are discussions of what is considered "successful" prevention, including how to determine whether research, once applied, has a positive impact. This likely stems from universal difficulty documenting ignitions that never occurred, a widespread challenge for prevention staff seeking to demonstrate the value of their programs. Many instead engaged the idea of "effectiveness" in prevention interventions, using pre- and post-surveys with an education intervention in between to document increased participant knowledge (e.g., Folkman 1966b; Bernardi 1970); however, it remains unclear whether that knowledge translated to behavioral change and ignition risk reduction beyond the study. We note that a majority of publications on fire prevention study Californian populations and were conducted prior to 1990, which may limit the generalizability of some findings and recommendations. The recommendations identified below should be interpreted and applied with consideration of these overarching themes.

Education

Education constitutes the most researched component of the fire prevention triangle. Much of this emphasis stems from the enduring presence of Smokey Bear as a national education campaign, though more recent conversations illuminate the limitations and consequences of Smokey's simplified message across diverse ecosystems, cultures, and relationships with fire (Donovan and Brown 2007; Minor and Boyce 2018; Vinyeta and Bacon 2024). Wetherill (1980) created a taxonomy of four types of wildfire prevention programs that engage education in various ways: (1) mass media, including signage, radio, and television communication; (2) mid-range

programs, ranging from school and community group programs to demonstrations and visitor center communications; (3) personal contact programs, which include direct contact with agency personnel and volunteers among other face-to-face interventions; and (4) law enforcement programs, organized into overt and covert operations. Categorization and distinctions between different programmatic efforts have since evolved, but agency prevention programs still strive to integrate a diversity of education approaches into risk reduction strategies. Table 1 overviews common best education practices and considerations as categorized by Wetherill; law enforcement programs are reviewed under a later section of this article. Missing from these existing education efforts are longitudinal or repeat studies of the same programs or populations to determine the enduring temporal impact of a given intervention. Additionally, education research tends to focus on the general public; rarely do these studies focus on a sub-population or interest group. Because little is known about the behaviors or impact of education on different subgroups (e.g., motorized recreationists, backpackers, international visitors), accurately tailoring outreach to diverse public land users is challenging.

Mass Media Public Service Announcements

Use of mass media, including television, radio, and print outlets, to share public service announcements (PSAs) was heavily studied as a cost-effective education approach for reaching large audiences in the 1960s and 1970s (Folkman 1975). Bernardi (1970) sought to understand audience attitudes towards three television PSAs – one that had no threat, one with mild threat, and one with strong threat related to wildfires – finding little difference among audiences in terms of their attitudes before and after, regardless of which PSA they were shown. This finding aligns with more recent studies that suggest fear appeals are not effective for motivating action related to wildfire risk reduction (Monroe and Nelson 2004; Cohn et al. 2008), although one study of predominantly Hispanic day use area recreationists found that fear appeals with a moral focus on impacts to communities was less effective than fear appeals based on fines or punishment when communicating fire restrictions (Cohn et al. 2008). A similar study where three television PSAs with different narrators – Smokey Bear, a youth, and a ranger – sharing identical information found that young adults were most affected by the youth narrator and presented more supportive stances regarding forest law enforcement, indicating that messengers with whom audiences identify are likely to elicit the strongest responses (Bernardi 1973). The timing of radio and television PSAs relative to scheduled content is important for capturing the attention of specific audiences (e.g., use of PSAs targeted towards hunters in between segments of an outdoor recreation or hunting show) (Folkman 1975); however, these spots are not guaranteed and often depend on the willingness of station or media staff to promote that message (Bernardi 1974). Mass media channels were also effective for reaching urban residents who travelled to public lands, though there appears to be no clear distinction between ignition risk posed by urban and rural public land users (Folkman 1979). Minimal literature was found that studied or discussed best practices for print media such as fliers or posters (Zobel 2024). As media consumption shifts to social media, internet videos, apps, and web

Table 1 Commonly reported best practices for education strategies to prevent human-caused wildfire ignitions

Activity	Reported best practices or considerations	Selected citations
Mass media PSAs	• Avoid messaging that focuses on fear or threat of fires; these have consistently been identified as ineffective • Use narrators or messengers that target audiences can identify with • Messaging should acknowledge the values of the target audience to build rapport and legitimacy • Align timing of radio and television PSAs to occur during scheduled programming that target audiences watch or listen to • Signage should include text that is minimal, direct, and minimizes misinterpretation • Use icons or symbols to improve signage recall • Mass media PSAs can be used to engage urban visitors who may bring fire risk to public lands given their higher visibility, particularly via television or billboard	Bernardi 1970, 1973, 1974; Folkman 1966b, c, 1975 1979; Evans 2018
Mid-range programs	• Program materials and in-person contacts should be shared by messengers who are perceived as legitimate and trusted among target audiences • Team teaching, particularly by pairs or groups from different agencies or entities, is most impactful in classroom settings • Develop place-based materials that can leverage audience interest and understanding (e.g., classroom curricula that focus on fire ecology in local ecosystems) • Develop unique or distinct programming for different public land user groups (e.g., hunters, campers, off-road vehicle users)	Folkman 1963, 1973; Ryan et al. 1978; Ballard et al. 2012; Devenport and Edgeley 2025

Table 1 (continued)

Activity	Reported best practices or considerations	Selected citations
Personal contact programs	• Place fire prevention staff at the forefront of face-to-face programs with the public • Coordinate and cross-train with local partners such as businesses and volunteer groups to expand capacity for face-to-face contacts • Provide staff training to enable appropriate and effective face-to-face communication • Ensure that financial and staffing capacity for face-to-face interaction is present to engage specific recreation groups that do not seek fire-related information from passive sources • Fliers and other education materials handed to a visitor in person are more likely to be read than signage; use of this kind of contact should be implemented strategically with the most pertinent information at the forefront	Folkman 1963; Sarapata and Folkman 1970; Doolittle et al 1975; Folkman 1979; Wetherill 1980; Nyame-Asaimah et al. 2023

pages, future communication efforts must explore prevention efforts in these spaces (Lindley 2022). Emerging studies in this space indicate that public land users now prefer to access fire information before and during trips via online platforms (Lindley 2022), although level of access over time varies significantly and declines during trips (Devenport and Edgeley 2025).

Studies of prevention signage, which are often identified by recreationists as a key information source (Folkman 1963; Devenport and Edgeley 2025), have focused on two aspects: the message shared on the sign, and the design of the sign itself, both with the intent to support improved recall. A study of two signs with the message "America Needs Productive Forests," one with and one without a Smokey Bear emblem, were presented to different audiences, revealing that the presence of Smokey improved recall and narrowed interpretations of the message (Folkman 1966b). Studies of the sign design itself have provided less clarity on optimal design; changes in signage colors may make them more noticeable but does not improve recall (Folkman 1964), while the development of new experimental signs about fire prevention did not improve recall among forest users either despite their novelty (Ruckel and Folkman 1966). Use of signs to prevent smoking in forests were more effective when the word "no" was added compared to identical signs with no text; however, the older the motorist viewing the sign, the less likely they were to interpret it correctly (Folkman 1966c). In northern New Mexico, signs showing illustrations of a shovel and spade accompanied by text reading "required for camping" to encourage campfire drowning were mistaken for messaging encouraging wilderness hygiene (Evans 2018). In sum, there is a lack of understanding about what makes signage truly effective as a fire prevention tool. Since many of these studies were published, signage has diversified to include both permanent and temporary electronic boards across or near roads; such signs likely reach non-local audiences and provide more nuanced, time sensitive information, meriting further study.

Mid-Range Programs

Mid-range educational programming refers to more targeted education efforts intended to reach specific groups or subpopulations, and can include approaches such as exhibits, school programs, community initiatives, demonstrations, meetings, workshops, and training programs (Wetherill 1980). Most existing research efforts are focused on assessing classroom- or school-based efforts catered to children and leveraged as an indirect education tool under the assumption that students will share information at home with their family, promoting cultural change surrounding fire safety over time (Block et al. 1976; Burnett and Edgeley 2021). Related instructional formats for prevention education are varied to align with varied environments, learning styles, and resource availability, and may include classroom visits, kits/trunks, camps/field trips, project-based service learning, small group discussions, or interpretive booths (Folkman and Taylor 1972; Ryan et al. 1978; Ballard et al. 2012). A study of a team-taught prevention program in California schools found that teachers valued use of legitimate messengers such as fire personnel as instructors, although

interpersonal skills such as approachability and positive interactions with students were also important (Ryan et al. 1978). Other studies emphasize the importance of designing unique programs for specific groups of recreationists (e.g., hunters) and find that those engaged in recreation activities that already require training or education programs gravitate towards similar approaches for fire prevention (Folkman 1963; Devenport and Edgeley 2025).

Building on concerns surrounding oversimplification of fire-related messaging from Smokey Bear, researchers also recommend incorporating some level of complexity (for example, discussion of basic fire ecology) into mid-range programs that can initiate greater nuance in public behaviors surrounding fire prevention (Jacobson et al. 2001; Ballard et al 2012). One effective mechanism for adding depth to mid-range programs is the development of place-based curricula and programing, for instance, through the development of lesson plans that focus on local landscapes or examples that target audiences already have a connection to (Folkman 1963; Ballard et al. 2012). That might include demonstrations or activities that use local vegetation, discussions of fire ecology that are specific to the local ecosystem, and case studies of recent nearby wildfires. However, questions remain about the overarching effectiveness of education programming as few studies have been able to meaningfully prove a relationship between education and declines in human-caused ignitions (Folkman 1973; Hesseln 2018). Other critiques include a perceived disconnect between those prioritized in education programs and those who present the greatest risk; for example, emphasis on school visits when children may be less likely to cause a wildfire than adults engaged in recreation activities such as target shooting (Simard and Donoghue 1987). Modernizing foundational research surrounding mid-range programs, such as the examination of message salience across different groups and efforts to document program impact on reductions in accidental or negligent ignitions, can place greater emphasis on the importance of investment in prevention programming.

Personal Contact Programs

Studies surrounding education-related outreach for wildfire prevention emphasize that face-to-face contact is foundational to risk reduction interventions, as reported by both members of the public and staff who initiate these contacts (Griessman and Bertrand 1967; Dickerson and Bertrand 1969; Sarapata and Folkman 1970; Doolittle 1972, 1980; Doolittle and Welch 1974; Doolittle et al. 1975). Personal contact programs are perhaps the most tailored of education efforts, focused on one-on-one or small group interactions that typically entail conversations focused on the audience's needs and values (e.g., a park ranger interacting with a hiker to share weather-specific information at a trailhead). Such efforts utilize agency personnel, local volunteers, businesses, or influential community leaders to engage relevant audiences (Wetherill 1980; Nyame-Asiamah et al. 2023). A study of urban visitors to forests in California found that those who were personally handed a list of fire prevention rules were more likely to read them than those who passed a sign with the same content (Folkman 1979). Face-to-face contact programs are also more heavily relied

upon by specific groups; for instance, hunters sought out personal contacts more frequently than impersonal sources in one California study (Folkman 1963). Some studies argue that agencies do not place enough emphasis on personal contacts and training of staff to support in-person communication efforts (Sarapata and Folkman 1970).

Enforcement

Enforcement occurs through the implementation of activity or access restrictions, enforced with the use of fines or criminal charges, and are typically conducted by law enforcement officers (LEOs) from local units such as police departments, Sheriff's offices, or land management agencies (Donoghue and Paananen 1984). Enforcement techniques are largely used to reduce recreational risks on public lands (Aslan et al. 2021) and reveal both support for fines and debates around whether fines related to wildfire ignition are too lenient (Griessman 1966; Sarapata and Folkman 1970). A limited amount of research investigates the use of enforcement tools in the context of fire prevention, often seeking to understand the behaviors that lead to illegal or unwanted intentional actions such as arson instead of negligent or accidental ignitions (Stanley et al. 2020). However, across the literature that does exist, scientists consistently underscore the interconnectivity between enforcement and education, often suggesting that enforcement should be a last resort in instances where education may resolve unwanted behaviors (Reynolds 1950; Wetherill 1980). Existing best practices and considerations related to enforcement interventions are summarized in Table 2.

Law Enforcement Staffing

The relationship between increased enforcement presence and decreases in illegal ignitions has been documented for almost a century (Fraser 1937). The presence of law enforcement alone has been identified as a deterrent for starting fires; in one study, a 1% increase in police officers per capita appeared to motivate a 0.094% decrease in arson incidents (Thomas et al. 2011), and a related study found that a 10% increase per capita would generate a 3.0% decrease in accidental wildland fires (Thomas et al. 2012). Similar results have been reported in other studies, finding that arrests reduce future arson ignitions in an area over time (Prestemon et al. 2019). Some studies suggest that public difficulty differentiating between law enforcement officers and other land management staff can create misplaced animosity towards agencies, necessitating education on the difference between positions within organizations such as the USDA Forest Service (Forest Service) (Reynolds 1950). Scheduling patrolling efforts to ensure greater capacity on high-risk days has been identified as an effective strategy for more than 80 years (Reynolds 1941); however, while an increase in enforcement staffing appears to reduce human-caused ignitions, capacity to recruit and retain additional positions is often limited within land management agencies.

Table 2 Commonly reported best practices for enforcement strategies to prevent human-caused wildfire ignitions

Activity	Reported best practices or considerations	Selected citations
Law enforcement patrols	• Issuing tickets, fines, or otherwise making contact with members of the public engaged in illegal activities that can cause wildfires should also be leveraged as an education opportunity • Education may be preferable to enforcement in instances where illegal activity was the result of lack of knowledge • Increased patrolling is often connected to a decrease in illegal ignitions; strategic patrolling increases during periods of high fire risk are most impactful • Communicate the difference between law enforcement officers and other forest staff to improve public relationships with land management agencies	Reynolds 1941, 1950; Cohn et al. 2008; Thomas et al. 2011, 2012; Prestemon et al. 2019
Access restrictions (e.g., area closures, forest closures)	• Regulatory approaches that restrict public land access are most likely to be supported by local residents in areas where human-caused fire occurrence and risk is high • Messaging should include explicit communication about what is and is not allowed, as agency terminology is not always clear to some members of the public • Extended access restrictions should be used with caution as they may result in permanent declines in visitation when re-opened	Folkman 1963; Hendricks et al. 2008; Devenport and Edgeley 2025
Activity restrictions (e.g., campfire policies, permits)	• Communication about restrictions that focuses on fines or other negative consequences are typically more effective than fear appeals • Restrictions on the use of axes, hatchets, and saws in combination with designated campfire policies can help achieve a balance between resource protection and visitor experience • Required use of campfire alternatives such as fire pans or propane fires may reduce campsite damage • Designated campfire locations may be preferable to campfire bans when building citizen-agency relationships (if it is safe to do so) • Campfire permits can build personal responsibility and accountability amongst members of the public while simultaneously serving as an education intervention	Reynolds 1950; Reid and Marion 2005; Cohn et al. 2008; Tymstra et al. 2020

Regulating Public Behavior

Several studies document the use of different kinds of restrictions as mechanisms for regulating public access and activities, particularly on public lands during periods of high fire risk. Campfire management is a prominent topic; the use of fire permits, currently used in Canada and a select few US states such as California, has been suggested as a tool for establishing personal responsibility and accountability amongst members of the public while also providing an opportunity to educate individuals prior to fire lighting (Reynolds 1950; Tymstra et al. 2020; McGee and Cabling 2022). Reid and Marion (2005) examined the effectiveness of three campfire policies–campfire bans, designated campfire locations, and unregulated campfires–in US national parks and forests, finding that lack of regulation typically resulted in far greater campsite damage and an increase in the number of fire sites. However, there was little evidence that campfire bans decreased the number of campfires or their related impacts; many studies highlight the cultural significance of campfires to recreational camping experiences which indicates that campfire regulations may be perceived as unnecessarily restrictive by public land users (Reid and Marion 2005; Brown et al. 2008; Lillywhite et al. 2013). Campfire bans have been identified as impactful in other contexts, such as producing decreases in burns-related hospital admissions (Hoang et al. 2013). Fire restriction communication efforts that focus on messaging legal or financial repercussions have been found to be effective with recreationists who identify with minority groups (Cohn et al. 2008). Non-recreational camping or illegal long-term residence on national forests has often been identified as a risk reduction concern, but limited documentation characterizes the nature or extent of that risk, or the effect that enforcement has on fire use among those populations (Baur and Cerveny 2019). Such studies indicate that there is a greater need for messaging related to the impacts of illegal campfire use, as well as demonstration of the benefits related to other approaches such as use of propane stoves.

Other restriction related mechanisms on public lands such as forest closures, stage restrictions, and area closures remain largely unstudied from a prevention perspective. Research that does exist tends to be outdated but indicates that terminology may be a barrier to understanding the requirements of such approaches; for instance, approximately one in five hunters did not know what the term “closed area” meant in a 1963 survey (Folkman 1963). Agency professionals in Canada felt that forest area closures were an effective tool for ignition risk reduction, but raised concern regarding their negative consequences for local economies; as a result, there was also higher interest in fire bans due to their greater flexibility (Tymstra et al. 2020). Support for regulatory strategies among surveyed visitors to several national forest ranger districts in the southwestern US was most common among Caucasian forest users and in locations where recent fire history was largely human-caused (Devenport and Edgeley 2025). Trail closures due to fire and related management activities that reduce the quality of a visit to public lands have been found to negatively impact recreationists’ place attachment, which may cause reduced visitation over time

(Hendricks et al. 2008). Future studies should seek to clarify the extent to which the public understands restriction-related mechanisms for fire prevention, their support for such techniques, and their effectiveness for reducing human-caused ignitions, in addition to the impact that restrictions might have on recreation displacement or redistribution (Edgeley 2023).

Engineering

Engineering interventions are designed to reduce the probability of an ignition by modifying the local environment and the ways in which humans interact and behave within it (Sarapata and Folkman 1970). Engineering typically consists of both infrastructural or interventions such as fuel treatments–for which there is abundant research exploring best practices (e.g., Kalies and Yocom Kent 2016; Davis et al. 2024; Hjerpe et al. 2024) –and smaller scale development (e.g., installing water sources, establishment of campfire rings, fencing to discourage access and reduce dispersed camping) intended to reduce the likelihood of unwanted human behaviors. Best practices and considerations for engineering approaches to prevention are shown in Table 3. Research on fuel treatments tends to be agnostic as to ignition source and instead focuses on effectiveness in changing fire behavior (Balch et al. 2017; Tedim et al. 2020); because natural and human ignitions are temporally and spatially different, this indicates a need to study fuel reduction specifically in the human-caused ignition context. Scant engineering-related research goes beyond fuels treatment and private property-related best practices; our search only uncovered relevant literature focused on campsite installations. Public support for engineering interventions may be more typical in remote areas or public lands where overnight camping is the most common form of recreation; recreationists on the rural Jemez Ranger District in New Mexico showed far greater interest in the addition of water sources and campfire rings than survey respondents in other more urban areas (Devenport and Edgeley 2025). Well-anchored fire sites, which can be created through permanent rock or metal fire rings, minimize unwanted encroachment of fires by clearly signaling a designated area for recreationists (Reid and Marion 2005). One wilderness study found that different interest groups indicated different acceptability of fire ring presence at camp sites, and that managers tend to be more tolerant of fire ring presence than public land users (Shelby and Shindler 1992). Other research indicates that human-caused ignitions are typically clustered around access-related infrastructure such as roads, campsites, or trail heads, indicating that prevention resource allocation is most cost effective at these locations (Narayanraj and Wimberly 2012; Benefield and Chen 2022).

Opportunities to research the relationship between engineering and fire prevention are vast. Many strategies in this space have received no attention; for example, the effectiveness of road signs (both static and digital) is often referenced as one of the most consistently accessed sources of information (Devenport and Edgeley 2025), but the impact of that effort is unknown. Alternative engineering strategies such as the use of shuttle busses to prevent unwanted vehicle ignitions

Table 3 Commonly reported best practices for engineering strategies to prevent human-caused wildfire ignitions

Activity	Reported best practices or considerations	Selected citations
Campsite installations	• Designation of campfire sites using metal fire rings or rocks can minimize unwanted damage and fire encroachment in and around designated campsites • Public land users in more remote places are more likely to support engineering interventions like campfire rings	Reid and Marion 2005; Devenport and Edgeley 2025
Other access/infrastructure related engineering	• Visitor access can be subtly modified through engineering techniques such as fencing, shuttle busses, reductions in dispersed camping opportunities, designated shooting areas, or parking lot vehicle caps to reduce opportunities to introduce human-caused ignition risks • Focus investments in engineering interventions at key public land access points where human-caused ignitions are most likely to occur to maximize cost effectiveness	Sims et al. 2005; Lawson et al. 2011; Narayanraj and Wimberley 2012; Benfield and Chen 2022

have been explored as a recreation management tool and identify high public support, but the potential implications for human-caused fire prevention are not yet understood (Sims et al. 2005; Lawson et al. 2011). Intentional assessment of the use and impact of engineering interventions that are already in place but not documented in the literature (e.g., designated shooting areas, installation of water sources) marks an important next step for improving scientific and practitioner understandings.

Administration

Combining education, enforcement, and engineering interventions offers the most comprehensive approach to human-caused wildfire prevention (Riebold 1957; Hesseln 2018; Devenport and Edgeley 2025). Administration that oversees these three facets of the fire prevention triangle must examine staffing, monitoring, and funding among other overarching considerations, nested within diverse local, state, and regional social and ecological contexts. The impact of prevention interventions appears directly related to the amount of funding available. Despite research that articulates the financial benefits of investment in prevention, agency budgets are reflective of this knowledge, more readily investing in suppression (Sarapata and Folkman 1970; Prestemon et al. 2010; Thomas et al. 2013). Table 4 summarizes best practices and considerations for prevention administration.

Fire Prevention Staffing

Approximately 400 fire prevention technicians were listed in the Forest Service budget in 2019, representing around 4% of the total number of employees whose positions are dedicated to fire-related activities (Kohler and Evans 2021). Prevention staff are often cross-trained for fire suppression activities and may be pulled away from prevention duties during peak fire season, creating an either/or scenario when it comes to prevention and suppression – a dual responsibility that has been advocated against in some instances (Riebold 1957; Kohler and Evans 2021). Studies of prevention staff most commonly assess employees' aptitude and personality relative to ignition data in their respective jurisdiction. Examination of characteristics that contributed to the "most effective" fire prevention personnel or contractors found that those who spent more than half of their time conducting contact activities with the public were perceived as most effective (Doolittle 1980). These individuals were more likely to be good communicators, accepting, achievement oriented, and driven by self-improvement; other factors like extroversion and conformity were not significant (Doolittle et al. 1975). Emphasis on personality traits aligns with other research that found the approachability of agency prevention educators in classroom education programs was a driver of perceived program success (Ryan et al. 1978). Despite emerging distinctions between effective and ineffective prevention staff, one study found little connection between an individual's effectiveness and opportunities for promotion or advancement within the Forest Service (Christiansen et al. 1976).

Table 4 Commonly reported best practices for administration strategies to prevent human-caused wildfire ignitions

Activity	Reported best practices or considerations	Selected citations
Fire prevention staffing	• Ensure alignment of understandings of what prevention entails between prevention staff and their supervisors • Increase opportunities for training among (1) prevention staff at lower levels, and (2) agency staff without prevention assignments, to support more consistent messaging and increased prevention capacity and retention • Maintain and increase funding and staff capacity for face-to-face prevention activities • Seek opportunities to create clear promotion pathways for prevention staff within agencies to protect institutional knowledge and retention	Christiansen et al. 1976; Doolittle 1980; Kohler and Evans 2021
Funding and administration	• Document and communicate cost avoidance produced by prevention efforts to underscore their value • Allow variation in the timing and duration of prevention program administration across local contexts to support fiscal responsibility and higher returns on investment • The public are willing to pay for both fire prevention and the opportunity to safely have campfires, indicating potential avenues for the diversification of prevention funding through permitting or recreation fees	Kaval 2009; Butry et al. 2010a, b; Prestemon et al. 2010; Lillywhite et al. 2013; Thomas et al. 2013; Abt et al. 2015; Alló and Loureiro 2020
Data management and evaluation	• Improve tracking of agency investments in prevention activities, programs, and staff to demonstrate their value • Standardize training and entry of ignition causes and related characteristics into local and national databases to improve data quality and evaluation capacity • Expand the amount of information collected regarding each documented ignition to support more comprehensive analysis • Invest in processes or frameworks for assessment of prevention effectiveness based on changes in human behavior	Folkman 1966a; Donoghue and Main 1985; Thomas and Butry 2011, 2012; Thomas et al. 2013; Kohler and Evans 2021

Prevention staff often judged their personal success differently from their supervisor, indicating a need for more consistent determination of what "success" means for fire prevention staff (Christiansen et al. 1976).

Absence of or limited funding for prevention relative to other programs like suppression was consistently identified as a challenge in studies of prevention staff (Sarapata and Folkman 1970). Research highlights capacity concerns among government employees who felt face-to-face prevention activities were most effective, but agency ability to undertake such efforts were limited by low staffing (Sarapata and Folkman 1970). Increasing the number of prevention staff can directly reduce the occurrence of human-caused wildfire ignitions within a jurisdiction (Prestemon et al. 2010); however, expanding staff is often financially infeasible, necessitating other administrative approaches to increase the effectiveness of prevention programming.

Economic Optimization of Prevention Programs

The need for greater funding of prevention and evidence that return on investment is high have both been documented for decades without related action in congressional or agency budgeting (Moak 1976; Christiansen et al. 1976; Bricker et al. 2008; Butry et al. 2010a; Prestemon et al. 2010; Abt et al. 2015). In a study of fire prevention efforts in Florida, Prestemon et al. (2010) reported that for every dollar spent on prevention, $35 in losses were avoided. Studies examining economic optimization of wildfire interventions found that a 20% increase in PSAs and prescribed fire would decrease the number of ignitions by 5.2% annually (Butry et al. 2010b). Leveraging the public as a supplementary funding source has also been explored in several instances. Households in a Spanish study were willing to pay around €111.70 (approximately $122) for the implementation of wildfire awareness programs (Alló and Loureiro 2020). Property owners in the Colorado wildland urban interface were willing to pay an average of $443 in additional taxes annually for local wildfire prevention activities; those who had created defensible space around their property were willing to pay even more (Kaval 2009). Despite these findings, there is no budget line item to track federal investments in fire prevention within the Forest Service and investment remains largely unchanged (Kohler and Evans 2021).

Return on investment in prevention efforts varies across programs, ecological conditions, social conditions, and seasons, making generalizable guidance on prevention investment difficult to produce (Butry et al. 2010a; Thomas et al. 2013). Simply shifting the timing of prevention efforts rather than altering the amount invested yielded state-level net benefits totaling $3.9 million in one Florida case study; in this context, every $1 million spent on prevention yielded $5.4 million in prevented wildfire losses (Butry et al. 2010a). The timing and duration of prevention activities has been consistently identified as a key factor for optimized prevention spending (Butry et al. 2010a; Prestemon et al. 2010; Thomas et al. 2013; Abt et al. 2015).

Data Management and Evaluation

Researchers and managers alike have made sustained calls for better documentation of human-caused ignitions, including their characteristics and contexts, arguing

that the most effective prevention programs depend on these data to guide their distribution and use (Doolittle and Donoghue 1991; Thomas and Butry 2011; Kohler and Evans 2021). Existing reporting systems for entering and tracking prevention data often document ignitions inconsistently because of varied user training, staffing capacity, and approaches between agencies that prevent comprehensive analyses (Folkman 1966a; Thomas and Butry 2012; Kohler and Evans 2021). The accuracy of efforts to determine the effectiveness of fire prevention efforts are reliant on the quality of these ignition documentation data as they offer a baseline for assessment and longitudinal monitoring (Lindenmuth and Keetch 1953; Thomas and Butry 2011; Thomas et al. 2013). Because current data in agency software such as InFORM are not entered consistently, quantitative efforts to demonstrate the net positive impact of prevention activities, particularly at regional or national scales, often rely on hypothetical or modelled data and largely focus on economic benefits related to prevention investments (e.g., Abt et al. 2015). Fewer studies examine empirical data that documents changes in human-caused ignitions as a result of prevention interventions. Agencies also lack a process or framework for assessing the effectiveness of public education efforts; in instances where this task has been undertaken, it is typically conducted using secondary data. Researchers have long argued for more consistent and comprehensive documentation of human-caused wildfire ignitions and related efforts to document human behaviors in order to improve the quality and impact of prevention programming (Wetherill 1982; Donoghue and Main 1985; Simard and Donoghue 1987; Thomas et al. 2013; Kohler and Evans 2021).

Discussion

Effective interventions to prevent human-caused ignitions on public lands play a critical role in social and ecological adaption to wildfire. Despite its effectiveness, prevention remains both underfunded and understudied. This review highlights a series of best practices for each prevention consideration–education, enforcement, engineering, and administration–revealing trends and gaps that merit further attention. Tailoring efforts to local contexts, with particular attention to the diversity of public land users and alignment with their values rather than use of fear appeals, is consistently shown to heighten their relevance. This means that prevention strategies can (and should) vary between agencies, districts, and user groups (Sarapata and Folkman 1970; McCaffrey et al. 2011; Chen and Jin 2022; Reilley et al. 2023; Devenport and Edgeley 2025). However, the existing social science surrounding prevention to inform the design and implementation of tailored approaches is outdated and merits updating to improve its relevance and effectiveness with today's public land users. Comprehensive documentation of the outcomes of specific strategies and the user groups they appeal to can help transition anecdotal assessments of prevention effectiveness into empirically informed decision-making that can aid more strategic staffing and resource allocation.

Existing prevention research that targets behavioral interventions is limited in both scale and scope, complicating the transferability of identified best practices and considerations outlined here and raising uncertainty about how to

tailor messaging across public land user groups. Much of the public lands-related research focuses on national forests, often in California by the Forest Service Pacific Southwest Research Station employees, limiting the social and geographic diversity of current knowledge. Additionally, while studies of different "modes" of prevention (e.g., education programs, signage, campfire rings) were common, few sought to understand related messaging or interpretation of these efforts by the public. In the few instances where messaging was explored, it was more common for these studies to occur in controlled environments such as focus groups rather than in the field. Lastly, many existing studies focus on one location, population, or prevention intervention; however, much of the research reviewed here advocates for a combination of approaches rather than use of one in isolation. To successfully implement a suite of prevention interventions across diverse public lands and user groups, prevention research must evolve to include comparisons between locations, interest groups, and activities across the fire prevention triangle. This will support the development of best practices that more closely align with the reality that prevention staff face while managing for a multitude of co-existing or competing social and ecological conditions.

Our review illustrates that social science related to wildfire prevention is, for the most part, extremely outdated; the vast majority of identified materials that focused on interventions with the public were published prior to 1990. More recent research has focused primarily on economic aspects of investments in prevention, but another way to improve cost–benefit is to ensure that interventions are as effective as possible – a consideration that requires current social science to determine and improve. There is an urgent need to modernize this field in several ways as human-fire interactions continue to increase and diversify. First, there is a need to reestablish a baseline understanding of support for, and best practices surrounding, behavioral interventions for fire behavior. Studies of widespread education techniques such as media campaigns and signage have not been conducted in more than 40 years, leaving uncertainty about whether these strategies and the messages they contain are still salient. Second, future studies must explore how advancements in technology affect prevention interventions. This might include use of the internet, phones, apps, social media, or electronic signage to communicate prevention messages and restrictions – most of which were not yet available when the majority of social science prevention studies were conducted. Given that culture and public land use continues to evolve, investigating the saliency of message framing on these platforms is also needed. Third, additional research is needed to examine a broader suite of engineering strategies than was available to managers in the 1900s; that might include consideration of increased accessibility, aided by improved outdoor equipment such as GPS and satellite phones. Studies of specific enforcement approaches (e.g., the impacts of a forest closures on the number of human-caused ignitions) are also needed – particularly as managers begin to leverage these tools more frequently while groups staying on public lands (e.g., transient or houseless populations, digital nomads) continue to increase and diversify. We also note that while an abundance of research has been conducted surrounding human ignition prevention on public lands, the same is not true of private lands. Extending prevention research to include private

landowners is timely as recent research suggests that ignitions originating on private lands more often transmit risk to public rather than the other way around (Downing et al. 2022). Box 1 provides an overview of key research gaps that could help advance prevention science and improve intervention effectiveness.

Box 1: Suggested topics and needs for future wildfire prevention research that can improve interventions to reduce human-caused ignitions on public lands.

- Understanding the impact of interventions across diverse public land user groups that are underrepresented in existing research (e.g., motorized recreationists, hunters, day use visitors)
- Characterizing whether demographic variables affect intervention preferences (e.g., international visitors versus locals, minority groups) in greater detail
- Conducting longitudinal studies that seek to understand the impact of a given intervention on the number of human-caused ignitions in an area or by a user group over time
- Determining the saliency of modernized messages and framing across public land user groups and locations, including the use of platforms like social media and new engineering techniques like electronic road signs
- Understanding differences between local and non-local public land users (e.g., language barriers/need for sign translation, differences in knowledge of fire prevention)
- Documenting the extent to which recreation displacement occurs during fire-related restrictions and closures, including whether displacement heightens risk in other areas
- Exploring the role of partnerships between agencies and other entities (e.g., local businesses, non-profits, interest groups, local or rural fire departments) in prevention messaging and intervention implementation
- Conducting social science prevention research across a more diverse assortment of public lands (e.g., national parks, tribal lands, Bureau of Land Management)
- Documenting patterns of enforcement activities and what they reveal regarding the content and placement of prevention strategies (e.g., analysis of citation recipient information or locations where citations are most frequent)
- Identifying barriers to investment in prevention, and the extent to which these differ across land management agencies
- Exploring how “success” and "effectiveness" are determined by prevention staff and land management agencies
- Characterizing differences in prevention efforts between public lands and private lands, the latter of which has received little attention
- Developing novel ways to determine the effectiveness of different intervention strategies and agreed upon metrics or criteria for tracking progress at different scales
- Conducting more comparative studies, whether that be prevention efforts across locations, between different user groups, or between intervention strategies, and the related tradeoffs of these decisions
- Improving study site selection justifications to better understand how local context influences data collection and findings

Administrators within entities tasked with prevention must make commitments to provide adequate staffing and resources for current and emerging research-driven best practices to be successfully implemented. Past studies consistently highlight the importance of a trusted messenger in the dissemination of prevention information (Folkman 1963; Ryan et al. 1978); this also indicates that large agencies like the Forest Service could increase their prevention capacity and impact by focusing on more cross-jurisdictional programming to heighten awareness and build relationships with public land users both locally and regionally. For example, increasing staff latitude for public engagement could support messaging in partnership with other nearby national forests. Furthermore, this demonstrates a need for multiple agencies in the same area to work collaboratively to replicate or tessellate messages and programming to complement one another as public land users cross jurisdictional lines (e.g., local governments, national forests, and national parks coordinating together).

Investment in interagency interventions at the local level can extend the reach and efficacy of small investments, particularly as wildfire risk transmission across public and private jurisdictions is well documented (Haas et al. 2015; Downing et al. 2022). The sustainability of investments in prevention also require an understanding of how prevention staff are currently operating. While many older studies examine the roles of prevention staff and their capacity to implement programming, agency funding and staffing levels have fluctuated significantly in recent years. This underscores the need for research to understand how prevention personnel conceive of their role within their agency, and how investment can go beyond programs and techniques to demonstrate the value of the individuals tasked with their implementation.

Progress in human-caused ignition prevention research and its implementation is also slowed by ambiguity at multiple levels that relate to agency characterization and understanding of interventions. The most centralized of these issues is the absence of a consistent definition of what "prevention" entails. While some published work argues that mitigation in the home ignition zone and fuels treatments constitute prevention, we suggest that though connected, these actions support loss prevention and limit fire spread, but do not prevent the ignition of a fire itself. The overgeneralization of what human-caused fire prevention entails prevents strategic investments from occurring, and limits meaningful administrative engagement in prevention on public lands; for example, the recent federal Wildland Fire Mitigation and Management Commission report does not directly address fire prevention or make recommendations related to it (US Wildland Fire Mitigation and Management Commission 2023). Amalgamated definitions of prevention also complicate agency ability to measure effectiveness of interventions; as many have noted (e.g., Donoghue and Main 1985; Thomas and Butry 2011; Thomas et al. 2013; Kohler and Evans 2021), measuring "prevented" unwanted fires is challenging, but clarity about what is being included in such measurements is needed to support progress and underscore the value of such activities. Measurement and monitoring are also complicated by advocacy for a constellation of prevention practices implemented simultaneously, which while more suited to the array of public land users present, makes it difficult to detangle the influence of each intervention individually.

This review has documented both existing best practices for human-caused ignition interventions and sheds light on the consequences that this now-outdated body of research has on effective administration of prevention activities on public lands. Current fire prevention staff knowledge far eclipses what has been documented in the literature; efforts to document current knowledge and best practices using rigorous social methodologies are critical for researchers to better support prevention personnel. We encourage clearer articulations of what prevention entails within each land management agency and suggest that this characterization can better focus administrative efforts around education, enforcement, and engineering to benefit both public land users and fire-ecosystem relationships moving forward. This requires strategic investment in both on-the-ground prevention and solutions-oriented research that can more comprehensively assess the impact of intervention approaches in tandem. Connected to this is the need for avenues to communicate local fire prevention challenges (e.g., staffing difficulties, funding barriers) to higher-level administration in order to invite systemic change in support for prevention among federal and state

land management agencies. The value of wildfire prevention is evident in the existing literature; aligning agency actions in ways that better recognize and incorporate this value into broader land management constitutes an important step towards a fire-adapted society.

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AME: Conceptualization, writing – review and editing, supervision, funding acquisition
SED: Conceptualization, investigation, writing – review and editing
GK: Conceptualization, writing – review and editing,
ZMZ: Conceptualization, investigation, writing – review and editing
WDD: Conceptualization, writing – review and editing

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