




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Untrammeling the wilderness: restoring natural conditions through the return of human-ignited fire

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Abstract

Historical and contemporary policies and practices, including the suppression of lightning-ignited fires and the removal of intentional fires ignited by Indigenous peoples, have resulted in over a century of fire exclusion across many of the USA's landscapes. Within many designated wilderness areas, this intentional exclusion of fire has clearly altered ecological processes and thus constitutes a fundamental and ubiquitous act of *trammeling*. Through a framework that recognizes *four orders of trammeling*, we demonstrate the substantial, long-term, and negative effects of fire exclusion on the natural conditions of fire-adapted wilderness ecosystems. In order to *untrammel* more than a century of fire exclusion, the implementation of active programs of intentional burning may be necessary across some wilderness landscapes. We also suggest greater recognition and accommodation of Indigenous cultural burning, a practice which Tribes used to shape and maintain many fire-adapted landscapes for thousands of years before Euro-American colonization, including landscapes today designated as wilderness. Human-ignited fire may be critical to restoring the natural character of fire-adapted wilderness landscapes and can also support ecological restoration efforts sought by Indigenous peoples.

Keywords Wilderness, Fire exclusion, Prescribed fire, Indigenous fire stewardship, Cultural burning, Untrammeled quality, Fire restoration

Resumen

Las políticas y las prácticas históricas y contemporáneas, incluyendo la supresión de fuegos iniciados por rayos y la remoción de fuegos intencionales iniciados por indígenas, han resultado en más de cien años de exclusión del fuego en muchos paisajes de los EEUU. Dentro de varias zonas determinadas como áreas silvestres, esta exclusión intencional del fuego ha claramente alterado los procesos ecológicos, constituyendo por lo tanto un acto fundamental y ubicuo de obstaculizar procesos naturales. A través de un marco conceptual de trabajo que reconoce cuatro órdenes de impedimentos u obstaculizaciones, demostramos los efectos substancialmente negativos y a largo plazo de la exclusión del fuego sobre las condiciones naturales de los ecosistemas naturales adaptados al fuego. En función de destrabar más de una centuria de exclusión del fuego, la implementación de programas activos de quemas intencionales puede ser necesaria en varios paisajes silvestres. También sugerimos un mayor reconocimiento y

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acomodamiento a las prácticas culturales de uso del fuego por parte de las comunidades indígenas, una práctica que los indígenas usaban para modelar y mantener los muchos de los ecosistemas adaptados al fuego por miles de años antes de la colonización Euro-Americana, incluyendo algunas zonas establecidas hoy como áreas silvestres. Los fuegos iniciados por los humanos pueden ser críticos para restaurar el carácter natural de los paisajes silvestres adaptados al fuego y también pueden ayudar a los esfuerzos eco-culturales buscados por los indígenas.

Introduction

As decades of past management actions prompt unintended ecosystem responses (Calkin et al. 2015), human pollution impacts even the remotest ecosystems (Feng et al. 2020), and climate change rapidly alters environments across the globe (Lee et al. 2023), the question of how to appropriately manage American landscapes designated as federal wilderness is increasingly urgent. Since the enactment of the 1964 Wilderness Act, wilderness managers have been tasked with balancing the Act's mandate to protect and preserve wilderness landscapes in their "natural conditions" while restricting human interventions in keeping with the Act's goal of preserving conditions "untrammeled by man." The question of what constitutes "natural" in wilderness fire management was one of many key issues recognized decades ago (Kilgore 1987) and remains at the heart of these tensions. Resolving them will likely require addressing the contradictions in imposing the Western concept of uninhabited wilderness to wilderness landscapes that, for thousands of years prior to Euro-American colonization, were affected by the intentional practices of Indigenous peoples (Kimmerer & Lake 2001).

In North America, historical and contemporary policies and practices, including the suppression of lightning-ignited fires and the removal of intentional fires ignited by Indigenous peoples, have resulted in over a century of fire exclusion; the resulting fire deficits have been capable of inducing widespread changes across many landscapes (Hagmann et al. 2021), including within designated wilderness areas. In many forested landscapes, fire-adapted ecosystems have undergone unprecedented structural and compositional changes as fire-sensitive species and small trees proliferate (Cocke et al. 2005), fuel loads increase (Hagmann et al. 2021; Keane et al. 2002), wildlife habitat degrades for some species (Hoffman et al. 2019), and ecosystem services diminish (Hurteau et al. 2014). At the same time, these changes to forests and woodlands are decreasing resilience to wildfire and climate change (Coop 2023; Prichard et al. 2021).

Attempts to completely remove fire from North American landscapes and the resulting ecological changes have only increased the likelihood of ecologically transformative wildfires (Calkin et al. 2015). In the pre-exclusion period, fires in many forests in the American West served

as a self-regulating mechanism, in that fires consumed fuel, thereby reducing the amount of fuel for the subsequent fire and perpetuating a fire regime dominated by low- to moderate-severity fire (Collins et al. 2009; Heyerdahl et al. 2001; Parks et al. 2014; Sherriff et al. 2014). In areas with a long history of exclusion, however, inevitable wildfires generally burn in a manner that is inconsistent with historical norms, meaning they burn at much higher severity and kill more trees than during the pre-exclusion period when fire was more frequent (Kreider et al. 2024; Parks et al. 2023; Williams et al. 2023). The inevitable wildfires in these fire-excluded forests are also causing some conversions to shrublands, grasslands, or other types that do not resemble long-standing reference conditions (Coop et al. 2020; Guiterman et al. 2022). For wilderness managers, charged by the Wilderness Act with preserving wilderness for present and future generations, the threat of significant and essentially permanent change to fire-adapted wilderness landscapes may be particularly troubling.

The restoration of fire as an ecological process has been espoused as a means to sustain the natural conditions of fire-adapted wilderness landscapes (Hessburg et al. 2015; Miller & Aplet 2016). However, some have argued that intentional ignitions are antithetical to the *untrammeled quality*, one of five wilderness qualities developed from the Wilderness Act to guide wilderness management (Miller 2006). As currently defined, any form of human intervention within wilderness, even actions intended to improve conditions, degrades the untrammeled quality (Landres et al. 2015), an understanding which many critique for being rooted in inaccurate assumptions about "uninhabited" wilderness which erase generations of Indigenous land stewardship. As framed by interagency sources, the suppression of fire *and* the ignition of prescribed fire are both interpreted as *trammeling actions*, or modern human manipulations that degrade wilderness character (Landres et al. 2015). While this framing has not prevented the widespread suppression of fires within wilderness,¹ it has been a barrier to the implementation

¹ The Wilderness Act makes special provisions for measures to control fire, insects, and diseases; this allowance has potentially increased the perceived acceptability of trammeling actions that support fire suppression objectives, including fire line construction and the use of aircraft, within wilderness.

of prescribed fire for many wilderness managers (CPL & ALWRI 2023; North et al. 2024; Yung 2008). This framing also falls short of engaging with one of the critical questions facing wilderness management in the twenty-first century: how can collaboration, respect, and partnership be increased between federal agencies and Indigenous peoples regarding wilderness management? Numerous lines of evidence demonstrate that the historical burning practices of Indigenous peoples across North America influenced landscapes that have been designated as wilderness (Berkey et al. 2021; Boyd 1999; Kipfmüller et al. 2021; Stewart 2002). Such Indigenous fire stewardship practices have continued to influence certain non-wilderness landscapes where they have allowed fire regimes to persist (Fulé et al. 2011), have restored fire regimes (Stan et al. 2014), or are restoring fire regimes (Long et al. 2020; Maclean et al. 2023). Given this, what are the implications—in both ecological and socio-cultural terms—of labeling intentional human-ignited fire as a trammeling action that degrades wilderness?

In response, we advance two concepts with important implications for wilderness fire management. First, we posit that the intentional exclusion of fire in wilderness over the last century demonstrates a clear alteration of historical ecological processes and thus constitutes a fundamental and ubiquitous act of *trammeling*. Rather than allowing wilderness to function “essentially unhindered and free” (Landres et al. 2015) in accordance with the untrammelled ideal, the exclusion of fire represents a significant action that controls wilderness. This concept builds upon the argument previously put forward by Indigenous fire practitioners: that environmental baselines should account for Indigenous burning and that fire suppression, rather than cultural burning, is an action that warrants consideration of environmental effects (Clark et al. 2021). Here, we conceptualize the substantial, long-term, and negative effects of fire exclusion on the natural conditions of fire-adapted wilderness ecosystems through a framework that recognizes *four orders of trammeling*—cascading actions that foreseeably result from fire exclusion over time.² In order to *untrammel* more than a century of fire exclusion, active restoration of fire, including intentional burning, may be necessary across large areas that include designated wilderness (see North et al. 2024).

Second, we suggest a reconsideration of the framing of human-ignited fire as a trammeling action within wilderness and present alternative terminology which could be introduced in acknowledgement of both Indigenous

practices of cultural burning and the ability of intentional fire to counter fire exclusion. Restoring human-ignited fire to fire-adapted wilderness landscapes is not only critical to restoring ecological resilience, but also in recognizing the stewardship practices of Indigenous peoples and providing opportunities for increased collaboration between agencies and tribal entities seeking *ecocultural* restoration through Indigenous cultural burning (Lake et al. 2017; North et al. 2024).

“First among equals”: The influence of the untrammelled quality on wilderness fire management

The Western concept of wilderness was codified into U.S. law by the 1964 Wilderness Act. The Act established the National Wilderness Preservation System and mandated that landscapes designated as wilderness be protected from development and preserved in their natural conditions for future generations. Today, over 111 million acres (45 million ha), about half of which are in Alaska, have received this designation comprising more than 800 wilderness areas. Four federal agencies have been charged with administering these areas, including the National Park Service (which manages approximately 40% of federal wilderness lands), the U.S. Forest Service (approx. 33%), the U.S. Fish and Wildlife Service (approx. 19%), and the Bureau of Land Management (approx. 9%) (“Wilderness Agencies” n.d.). In addition to these federal agencies, several Tribes manage areas either labeled as or managed in keeping with wilderness principles, including the Confederated Salish and Kootenai Tribes (Mission Mountains Tribal Wilderness), Taos Pueblo (Blue Lake Wilderness), and the White Mountain Apache Tribe (Dził Łigai Si’an Tribal Wilderness, formerly the Fort Apache Indian Primitive Area).

The question of how to appropriately manage designated wilderness has been actively debated for decades. The Wilderness Act defines wilderness as “an area where the earth and its community of life are untrammelled by man, where man himself is a visitor who does not remain.” The Act then mandates that the administering agencies manage these landscapes “so as to preserve [their] natural conditions.” From these two directives—developed by the agencies into the *untrammelled* and *natural* qualities—a central tension of wilderness management has emerged. Under the untrammelled quality, interagency strategy calls for wilderness landscapes to function “essentially unhindered and free from the intentional actions of modern human control or manipulation” (Landres et al. 2015). Thus, even management actions undertaken to achieve positive ecological outcomes are considered a degradation of the untrammelled quality. However, the preservation of natural conditions,

² This conceptualization builds upon the three orders of wildfire effects introduced by Ryan et al. (2012).

defined as “the indigenous species compositions, structures, and functions of the wilderness” (Landres et al. 2015), has at times required some degree of intentional human action, for example, to limit the spread of invasive species or restore rare biota (Lieberman et al. 2018). Today, wilderness managers must often navigate between the untrammeled and natural qualities as they consider how to manage wilderness landscapes.

This management dilemma becomes even more complex with the recognition of the influence of Indigenous peoples in shaping and maintaining the character of many wilderness landscapes prior to Euro-American colonization (Anderson & Barbour 2003; Kipfmüller et al. 2021; E. R. Larson et al. 2021; Watson et al. 2011). Critiques of the Western concept of wilderness advanced by the Wilderness Act frequently focus on the erasure of humans from protected landscapes (Spence 1999; Vinyeta 2022), which Hendlin (2014) identifies as “pit[ting] conservation ahistorically against the indigenous communities often living in these ecosystems.” This raises further questions about what might be considered a natural ecological regime within wilderness. Sources indicate that some early wilderness conservationists considered Indigenous influence to be part of the natural ecosystem (Kilgore 1985), with one influential wilderness report stating: “Early day [Indigenous] activities have also had a significant impact on original natural conditions in some areas so these must be included in any total view of wilderness” (The Wildland Research Center 1962). However, the untrammeled quality arguably remains the most prominent consideration in wilderness management today.

While both the untrammeled and natural qualities are used to assess whether or not a wilderness is being preserved or degraded (in conjunction with three other wilderness qualities derived from the Wilderness Act³), the untrammeled quality is specifically given extra weight as a tiebreaker (Landres et al. 2015). Per interagency strategy, if an equal number of wilderness qualities are expected to be preserved as degraded by a proposed action, deference is given to the untrammeled quality, which is considered first among equals (Landres et al. 2015). In practice, this positions strict restraint—i.e., no intervention—over other wilderness characteristics like the natural quality, thus upholding an ideal of wilderness as, first and foremost, uninhabited and uninfluenced by people. That position, combined with the labeling of prescribed

fire as a trammeling action in interagency strategy (Landres et al. 2015), has led some managers and stakeholders to commonly presume that the Wilderness Act does not allow prescribed fire in wilderness, which is false (CPL & ALWRI 2023; Forest Service Manual 2007). Even as fire exclusion negatively impacts the natural quality of many wilderness landscapes, the untrammeled quality as currently conceived and positioned creates substantial barriers to the restoration of fire.

Landscapes across North America were shaped by Indigenous fire for thousands of years

Research indicates that early humans used fire to modify their environments to their advantage nearly 100,000 years ago (Thompson et al. 2021). In North America, many Indigenous peoples have used fire to influence the environments in which they live and steward from time immemorial (Hankins in press 2024; Christianson et al. 2022; Kimmerer & Lake 2001; Lewis 1973). For example, the Anishinaabeg historically ignited fires along commonly traveled waterways in what is today the Boundary Waters Canoe Area Wilderness in Minnesota (Kipfmüller et al. 2021). This practice contributed to opening forest understories, more favorable for resting and camping; promoted the production of blueberries, a staple subsistence crop; and influenced the establishment of red pine stands, a fire-adapted species (Larson et al. 2021). In California, the Yurok and Karuk Tribes use cultural fire to enhance their ancestral landscapes for a diversity of reasons, including the enhancement of fire-stimulated California hazelnut stem production, an important material for traditional basket making (Marks-Block et al. 2021). Along with lightning-ignited fires, these human-ignited fires have helped shape fire regimes in many areas, with ecosystems developing and renewing in response to the frequency and severity of the fires they experienced (Knight et al. 2022; Roos et al. 2023).

In the American West, where most wilderness areas are located within the contiguous USA, an era of unprecedented fire exclusion began in the late-1880s. Rising anti-fire sentiment coincided with, and was often propelled by, colonization. While some Euro-American colonizers ignited fires in ways that followed preceding Indigenous burning practices (Fowler & Konopik 2007; Stewart 2002), government authorities, increasingly concerned with preserving valuable resources such as timber, began to explicitly criminalize intentional burning practices around the turn of the twentieth century (Andrews 1900; Christianson et al. 2022; Marks-Block & Tripp 2021, Hankins in press 2024). The introduction of widespread livestock grazing in certain regions, particularly in the American Southwest, also influenced fire regimes

³ In addition to the (1) untrammeled and (2) natural qualities, wilderness managers must assess the impact of management actions on the (3) undeveloped quality; the (4) solitude or primitive and unconfined recreation quality; and the (5) other features of value quality (Landres et al., 2015).

through the removal of fine fuels that previously supported frequent surface fire (Guiterman et al. 2019; Swetnam et al. 2016). In 1910, a series of large and devastating fires in northern Idaho and western Montana collectively burned three million acres (1.2 million ha) and killed 85 people, inflaming concerns about fires. By 1911, the newly established U.S. Forest Service had been expanded to bolster the agency's firefighting capabilities as the de facto national fire policy became one of total suppression (Minor & Boyce 2018). Along with these new policies and practices came the active vilification of human-fire relationships. Fire was depicted as a mortal threat to both people and timber, with the ignition of fires portrayed as, at best, carelessness and at worst calculated malice (Kosek 2006). This response to wildfire may have been, in part, a survival response by Euro-American colonizers: population growth in the American West had brought structures and modern industries to landscapes that could be impacted by fire in ways that earlier socio-cultural landscapes were not. However, attempts to completely exclude wildland fire have often led to widespread negative effects across landscapes.

Four orders of trammeling: a framework for understanding the consequences of fire exclusion on wilderness landscapes

The exclusion of fire due to fire suppression, the removal of Indigenous peoples and their practices, livestock grazing, and landscape fragmentation has substantially altered the form and function of many wilderness ecosystems. Fire has long been a significant evolutionary driver for many species within fire-prone environments, influencing traits such as resprouting, serotiny, and germination by heat and smoke (Bond & Keeley 2005; Keeley et al. 2011). In this and other ways, fire has shaped entire communities of life, from the structure and composition of ecosystems to the historical presence of humans, who often relied on fire to make landscapes habitable (Larson et al. 2021; Nowacki & Abrams 2008).

Fire exclusion results in multiple orders of effects (Fig. 1). The first order of trammeling is the exclusion of fire from a fire-adapted wilderness landscape which interrupts the natural process through the suppression of lightning-ignited fire; the impairment or inability of fire to spread due to landscape fragmentation and livestock grazing; and the removal of Indigenous peoples in areas where they exerted significant influence on landscapes through practices of intentional burning (Roos et al. 2022). This first order trammel is ubiquitous across fire-adapted wilderness landscapes (Lieberman et al. 2018; North et al. 2015).

The second order trammel, which results as an indirect effect from the first order trammel, takes place as forest

structure and species composition increasingly depart from historical conditions and forest landscapes become more homogenous as fire-generated openings and early seral vegetation types are lost across a range of spatial scales (Hessburg et al. 2019). Without fire to reduce new growth and consume dead, downed, or fire-sensitive trees, fuel loads and forest density increase with greater horizontal and vertical fuel continuity (Calkin et al. 2015; Keane et al. 2002). In certain cases, fire-adapted species may be outcompeted by fire-sensitive species with greater tolerance for increasingly shady forest conditions (Nowacki & Abrams 2008). This shift in plant species can lead to mesophication, a positive feedback cycle in which conditions for shade-tolerant fire-sensitive species continue to improve as conditions for fire-adapted species continue to worsen, a process which makes the restoration of fire-adapted ecosystems increasingly difficult. In some instances, the alterations to forest composition and structure resulting from these impacts have no ecological antecedent (Nowacki & Abrams 2008). An additional impact of second order trammeling can be seen in the Mount Lassen Wilderness, where fire exclusion has been identified as a probable factor leading to the Lassics lupine (*Lupinus constancei*) listing as an endangered species in 2023 (Endangered Species Status for Lassics Lupine 2023). Specifically, the encroachment by conifer trees (i.e., the second order trammel) into the Lassics lupine's serpentine barren habitat may have led to increased seed predation by mammals and increased competition for resources.

The third order of trammeling occurs when uncharacteristically severe and large fires burn through altered wilderness ecosystems and induce further alterations of ecological composition, structure, and processes, sometimes resulting in conversions from forest to other vegetation types (Coop et al. 2020; Fig. 2). Forecasts have indicated the potential for startling changes, with models predicting that in the Intermountain West between 1.6 and 15.1% of forested areas could be at risk for fire-driven conversion to non-forest by the mid-twenty-first century depending on ecoregion; in the Southwest, up to 30% of forested areas may be vulnerable to type conversion (Parks et al. 2019). These fire-catalyzed changes are becoming more common and result from the combined effects of fire exclusion and climate change (Coop et al. 2020; Davis et al. 2019; Stevens-Rumann et al. 2018). In addition to type conversion, uncharacteristically severe fires may also trigger debris flows that can negatively impact water quality, cultural resources, downstream infrastructure, and wildlife. For example, wildfire-induced debris flows in the Gila Wilderness extirpated populations of Gila trout, a federally listed species (Holden et al. 2009).



Fig. 1 Graphic shows the *four orders of trammeling*—cascading actions that foreseeably result from fire exclusion over time

Finally, the fourth order trammel occurs when previously unnecessary management interventions are undertaken in wilderness in an effort to salvage or restore ecological elements in the wake of uncharacteristically severe fires. Even as these actions seek to improve conditions, they are considered degradations of the untrammelled quality (Landres et al. 2015). An example can be seen in the Bandelier Wilderness, where 800 seedling trees were planted in 2020 within the footprint of the 2011 Las Conchas Fire. These actions were taken to counteract the limiting effects on natural regeneration resulting

from canopy loss caused by the high-severity fire effects of the Las Conchas Fire, as well as predicted regional weather trends which forecast increased dryness (Hafey et al. 2018). Similarly, plans are currently underway to plant giant sequoia seedlings, with helicopter support, in the Sequoia-Kings Canyon and John Krebs Wildernesses (Ortega-Welch 2023). This action has been prompted by uncharacteristically severe wildfires which have caused large-scale loss of adult sequoia trees, a species which historically thrived with fire (Speck & Speck 2024). Preliminary estimates suggest that the 2020 Castle Fire alone



Fig. 2 Photos show historically forested landscapes following uncharacteristically severe fires. **A** A heavily impacted dry mixed-conifer forest in the Cache La Poudre Wilderness in Colorado following the 2012 High Park Fire. **B** Fire-killed giant sequoias in Sequoia and Kings Canyon National Park in California following the 2021 KNP Complex. **C** Massive mortality in a Douglas-fir forest in the Gila Wilderness in New Mexico following the 2006 Bear Fire and the 2012 Whitewater-Baldy Complex. **D** Repeated high-severity fires have changed a forested site into a shrub field in the Dome Wilderness in New Mexico

killed between 7,500 and 10,600 sequoias with trunk diameters of four feet or greater, or 10–14% of the large sequoias across the Sierra Nevada range (Stephenson & Brigham 2021). A survey of giant sequoia groves that burned between 2015 and 2017 revealed that approximately 84% of legacy giant sequoias were killed by high-severity fire (Shive et al. 2022).

Human-ignited fire can untrammel wilderness landscapes

Where a century of fire exclusion has imperiled many fire-adapted wilderness landscapes, intentionally ignited fire may be a critical tool to restore these systems (Coppoletta et al. 2019; Hunter et al. 2014; Keifer 1998; Keifer et al. 2000; Parsons et al. 1986). The benefits of prescribed fire in reducing fuels, increasing ecological resilience, and restoring historical conditions have been noted in both wilderness and comparable areas. For example, in Sequoia and Kings Canyon National Parks, where the first federal prescribed fire program was established in 1968 (Miller 2020), scientists recorded a 71% reduction in the total fuel load of study plots immediately following a prescribed burn, with the total fuel load remaining below pre-fire levels for the subsequent 10 years (Keifer 1998). Prescribed fire reduced the density of trees, with the largest reduction being smaller trees, while bringing the forest structure within pre-colonization ranges (Keifer

et al. 2000). Similar findings were made in a study of prescribed fire and managed lightning-ignited fires in the Saguaro Wilderness and the Gila-Aldo Leopold Wilderness Complex (Hunter et al. 2014). In the Indiana Summit Research Natural Area, areas treated with prescribed fire in the late 1990s were found to burn less severely during a 2016 wildfire when compared to untreated areas, with bole char three times lower and tree scorch height two and a half times lower (Coppoletta et al. 2019). Areas treated by prescribed fire also maintained the same density of large trees (often valued as legacy trees) post-fire, while untreated areas saw declines of large trees up to 50% (Coppoletta et al. 2019). Additionally, research has indicated that intentional burning allows for the reintroduction of fire with fewer risks (e.g., fire escaping the wilderness) when compared to the management of lightning-ignited fires, including keeping conditions within the range of effects that would be expected under historical fire regimes (North et al. 2024; Parks et al. 2023).

Consequently, human-ignited fire could be considered an *untrammeling* of wilderness: over time, the first and second order trammeling associated with fire exclusion can be mitigated through active programs of intentional fire that decrease the likelihood of third and fourth order trammeling and facilitate the return of lightning-ignited fire under a broader range of conditions. Forests with relatively intact fire regimes do not display comparable



Fig. 3 As fire exclusion induces ecosystem conditions to change, wilderness managers may feel increasing pressure to use mechanized equipment and other high impact suppression activities within wilderness to mitigate uncharacteristically severe wildfires. In these photos, the impact of a bulldozer, used to create fireline during the 2021 Dixie Fire, can be seen in the Bucks Lake Wilderness in California (Courter 2021). Treating wilderness landscapes with prescribed fire may lessen the need for suppression tactics like this in the future

changes in structure and composition nor have they experienced the uncharacteristically severe wildfires which are affecting their fire-excluded counterparts (Hagmann et al. 2021; Parks et al. 2023). As fire regimes are restored through human-ignited fire, the probability of uncharacteristically severe fires and conversion to non-forest decreases (Walker et al. 2018), with intentional burning additionally able to buffer climate impacts on wildfire activity (Roos et al. 2022) and on subsequent vegetation response (Davis et al. 2023). Additionally, the reduction of fuel and increases in fuel heterogeneity through intentional burning increase the capacity and ability of wilderness managers to manage lightning-ignited fires (Fig. 3). This rationale has been cited in prescribed fire plans for the Mission Mountains Wilderness (Mission Upland Burning Project 2011) and the Boundary Waters Canoe Area Wilderness (Hi Lo Project 2018).

It is worth noting that the extent to which a specific landscape's fire regime has been disrupted varies from landscape to landscape across (and even within) wilderness areas, with some landscapes much more affected than others. For example, low- to mid-elevation forests dominated by species such as oaks, ponderosa and sugar pine, Douglas fir, and giant sequoia generally experienced fairly frequent low- to moderate-severity fires ignited by both lightning and people, whereas cold, high-elevation forests (e.g., spruce-fir) generally experience less frequent but higher severity fire (Heyerdahl et al. 2008; Schoennagel et al. 2004). However, cooler and wetter forest

types also reflected influence of Indigenous populations, including maintaining openings and desired vegetative communities (Hankins 2013; Kipfmüller et al. 2021; Knight et al. 2022). Because of these variations, the reintroduction of human-ignited fire is more appropriate in some wilderness landscapes and less appropriate in others.

Many experts, researchers and scholars from agencies, Tribes, and conservation organizations have increasingly identified prescribed fire as a needed management practice (Botti & Nichols 2021; CPL & ALWRI 2023; Kolden 2019; Prichard et al. 2021). Despite such recognition of the benefits of human-ignited fire, its use has been limited. From 1998 to 2018, prescribed burning in the Western USA has remained stable or decreased, with the Bureau of Indian Affairs as the only agency to notably increase its use of prescribed fire (Kolden 2019).

Management of lightning-ignited wildfires has largely failed to restore fire to wilderness

Where federal agencies have attempted to restore fire to wilderness, it has predominantly been through the management of lightning-ignited wildfires. The release of the influential Leopold Report in 1963, which acknowledged fire as a critical management tool, and a growing body of research detailing the benefits of fire, helped precipitate shifts within the scientific and land management communities, which had long resisted the idea that fire could benefit ecosystems (Miller 2020). Changes to fire

management began to follow. In the late 1960s and early 1970s, the National Park Service and the Forest Service established fire management programs in Sequoia and Kings Canyon National Parks, the Selway-Bitterroot Wilderness, Saguaro National Park, Yosemite National Park, Yellowstone National Park, Grand Teton National Park, and the Gila Wilderness (Kilgore 1987; R. Miller 2020; van Wagtenonk 2007). The aim of these programs was to allow wildfires to burn for ecological benefit so long as they could be contained within specified zones (van Wagtenonk 2007).

However, the management of wildfires across the broader National Wilderness Preservation System has largely failed to restore historical fire regimes and their associated ecological conditions over the course of decades. In part, this is due to lack of implementation. While wilderness policy supports allowing wildfires to burn within wilderness areas, in practice this has been rare (Aplet 2006). While reporting and classification discrepancies among the four agencies managing wilderness make data difficult to compile, research indicates that most wilderness areas continue to default to full suppression (Long & Biber 2014; Parsons 2000; Seielstad 2015). In a survey of management interventions taken within wilderness between 2011 and 2015, wildfire interventions were found to be the second most common type, with the establishment of firelines and extinguishment of lightning ignitions as the most common actions (Lieberman et al. 2018). Notable exceptions in the Western U.S. include large wilderness areas such as the Gila Wilderness, Selway-Bitterroot Wilderness, Frank Church-River of No Return Wilderness, Bob Marshall Wilderness Complex, and Yosemite Wilderness, where decades-long programs have successfully allowed lightning-ignited fire to play an ecological role across landscapes (Berkey et al. 2021; Hunter et al. 2014; van Wagtenonk 2007). Although not all fires over the last several decades in these areas burned in a manner consistent with historical norms (e.g. Keane et al. 2006), a growing body of literature suggests that these wildernesses are generally resilient and well-positioned for continued policies of managing wildfires (Boisramé et al. 2019; Jaffe et al. 2023; Kreider et al. 2023; A. J. Larson et al. 2013; Parks et al. 2018; Stephens et al. 2021).

The management of wildfires is further complicated by contemporary ecological conditions, which are more likely to prompt uncharacteristically severe wildfires that may be out of step with historical fires (Parks et al. 2023; Williams et al. 2023). Rather than promoting ecosystem health, some wildfires may produce negative effects. For example, in the Bob Marshall Wilderness in Montana, return of fire following a century of exclusion resulted in

mortality of one-third of old ponderosa pines because of cambial girdling, which in turn resulted from high fuel build up around trees (Keane et al. 2006). Even in such a remote area, scientists suggested that interventions such as thinning, pile burning, raking, and prescribed understory burning would be required, in addition to relying on managed lightning ignitions, to sustain the old-growth pine trees in the wilderness (Keane et al. 2006; but see Larson et al. 2013). Every year, growing fuel loads and the hotter and drier conditions associated with climate change only increase the difficulty and complexity of managing increasingly risky wildfires (Calkin et al. 2015).

Attempting to exclusively rely on lightning-ignited managed wildfires to restore fire regimes also fails to account for the influence of Indigenous land stewards, which may have been significant across certain landscapes. For example, the fire practices of Anishinaabeg peoples in the Border Lake region between Minnesota and Ontario, Canada, likely increased the abundance and distribution of open red pine forests within today's Boundary Waters Canoe Area Wilderness, an example of the ability of humans to amplify landscape vegetation patterns (Larson et al. 2021). Similarly, the extensive influence of Indigenous peoples on forests, woodlands, and grasslands have been well-documented in the western USA (Knight et al. 2022; Metlen et al. 2018; Roos et al. 2023; Skinner et al. 2009; Taylor et al. 2016). Thus, even if federal agencies were able to manage wildfires at the greatly increased scale necessary to restore historical fire regimes, these important human influences would remain absent.

Restoring human-ignited fire to wilderness landscapes

Intentional burning in many wilderness areas may be warranted both for its value in redressing the effects of a century of fire exclusion and in restoring the recognized role of Indigenous burning across many of these landscapes. While interagency strategy lists management-ignited fire as a trammeling action (Landres et al. 2015), it does not directly address present-day Indigenous cultural burning, a practice distinct from prescribed burning by federal personnel (Eriksen et al. 2014; Hankins et al. 2013; see Table 1). Interagency sources do state that the concept of trammeling “does not apply to manipulations that occurred before wilderness designation (such as the use of fire by indigenous people to promote game habitat) because the mandates of the Wilderness Act do not apply prior to designation” (Landres et al. 2015). However, this exception is grounded in a legal understanding of the wilderness designation and does not address present-day Indigenous stewardship practices. As has been

Table 1 Important distinctions between Indigenous cultural burning by Tribes and the use of prescribed fire by federal personnel

While cultural burning by Indigenous peoples and the use of prescribed fire by federal personnel are both examples of human-ignited fire, they are distinct practices and important to recognize as such. Cultural fire has been defined as the “purposeful use of fire by a cultural group (e.g., family unity, Tribe, clan/moiety, society) for a variety of purposes and outcomes” (Clark et al. 2021). These ignitions may be accompanied by specific cultural practices, as well as pre- and post-fire preparation and monitoring in line with Indigenous land stewardship traditions (Long et al. 2021). By contrast, ignitions of prescribed fire by federal agencies are often focused more narrowly on objectives such as wildfire risk reduction; are often not as frequent or integrated with other practices such as harvest; and do not have a deep cultural basis. While both rely on humans as ignition sources, Indigenous cultural burning and prescribed fire ignited by agencies remain essentially distinct even though they can achieve similar outcomes in terms of maintaining and increasing forest health and resilience.

suggested, the potential exists to reexamine contemporary understandings of wilderness in order to recognize and affirm the stewardship practices of Indigenous peoples (Hendlin 2014; Larson et al. 2021; Mistry & Berardi 2016; Nie 2008).

Through increased engagement with Tribes, agencies administering wilderness could better understand tribal perspectives and concerns regarding cultural burning and other traditional practices, as well as the ways in which federal policies are impacting tribal rights. For example, in the Karuk Tribe’s high country in northwestern California, much of which is designated wilderness, fire suppression has been a primary intervening stressor producing negative ecological *and* cultural effects in some of the Tribe’s most spiritually important places. Fire suppression actions have damaged physical artifacts and contributed to the erasure of vegetation patterns which serve the Karuk as cultural knowledge archives of past stewardship practices, thus impairing their ability to learn from their ancestors and the land (Norgaard & Tripp 2019). This experience is not unique to the Karuk Tribe, with fire suppression activities resulting in significant cultural and ecological impacts to Tribes and tribal lands across the USA (Christianson et al. 2022; Clark et al. 2021; Kipfmüller et al. 2021; Larson et al. 2021; Long et al. 2021). For many Indigenous peoples, the revitalization of cultural burning is a priority (Adlam et al. 2022; Lake et al. 2017; Maclean et al. 2023; Marks-Block et al. 2021).

Consideration might also be given to the framing of human-ignited fire as a trammeling action, given the historical role and continuing ecocultural importance of Indigenous burning and the ability of intentional fire to *untrammel* over a century of fire exclusion. Additional terminology, for example, such as a *legacy trammel* or *counter-trammel*, could be introduced to acknowledge the unique historical legacy of human-ignited fire *and* the critical present-day role of intentional burning in countering fire exclusion. New terminology might help to reduce friction around the use of prescribed fire in wilderness—a known barrier to fire restoration (CPL & ALWRI 2023; Yung 2008)—as well as promoting increased collaboration between agencies and Tribes.

Many wilderness experts have long recognized the significance of Indigenous burning and suggested that it presented a rationale for prescribed burning. For example, the Outdoor Recreation Resources Review Commission, formed by Congress in 1958 to recommend sustainable land management policies, included a report that acknowledged the role of Indigenous burning in shaping ecosystems and identified prescribed fire as a possible management alternative within wilderness (The Wildland Research Center 1962). The use of fire by Indigenous peoples and the issue of deliberate ignitions by managers was a major focus of a 1983 wilderness fire symposium sponsored by the Forest Service and National Park Service (Lotan et al. 1983), and was raised continuously in a state-of-knowledge review of wilderness fire presented at a 1987 national wilderness conference (Kilgore 1987). Prominent early scientists in the field of fire ecology vocally recommended the use of prescribed burning within wilderness on the basis of past fire regimes which included human-ignited fire (Heinselman 1965; Kilgore 1972). Similarly, influential members of the Leopold family recognized and raised for discussion the ecological necessity of fire within wilderness over the course of four decades (Parsons 2000).

Fruitful discussion may result from a consideration of the ways in which intentional fire can be used in wilderness to achieve objectives of the Wilderness Act. Both cultural fire and prescribed fire can help restore and maintain the natural conditions of wilderness. Anderson and Barbour (2003) and Wray and Anderson (2003) urged the National Park Service to go beyond simply restoring lightning fires and instead seek to simulate Indigenous fire stewardship. In some wilderness areas, Indigenous fire practitioners themselves are seeking to resume these practices as a right and responsibility (Norgaard & Tripp 2019). With substantial financial and human resources, federal agencies may be able to apply prescribed fire in ways that facilitate restoration of more natural conditions and enhance the ability of Indigenous fire practitioners to tend cultural fires. Similarly, increased exposure to cultural fire and increased collaborations with Indigenous fire practitioners may serve to deepen the understanding of federal staff regarding the role of human-ignited

fire within wilderness landscapes. Thus, prioritizing fire restoration through human-ignited burning can enhance the preservation of wilderness values, redress a long overdue institutional recognition of the role of historical Indigenous fire in shaping these landscapes, and increase opportunities to partner with Tribes seeking ecocultural restoration using fire in ancestral lands (Lake et al. 2017).

Pathways forward

Many voices have called for restoring human-ignited fire to wilderness for decades (Heinselman 1965; Kilgore 1987; Lotan et al. 1983). A recent report advancing this effort identified several opportunities to overcome barriers to implementing prescribed fire in wilderness. These opportunities include, for example, encouragement by agency leaders of the appropriate use of prescribed fire; consistent interagency messaging and guidance to wilderness staff which affirms the presence and continuing importance of human-ignited fire; and proactive and far-reaching engagement with the public about the role of fire within wilderness, both historical and present-day (CPL & ALWRI 2023). Additionally, policymakers could consider allowing the use of prescribed fire to meet a more expansive range of objectives, including the use of such burns for biological, ecological, and cultural conservation and restoration. Currently, the agencies managing wilderness restrict the ignition of prescribed fires in a number of ways. For example, the Forest Service permits the use of prescribed fire in wilderness to reduce unnatural buildups of fuel, but not to meet other objectives, such as for the benefit of wildlife, maintenance of vegetative types, improvement of forage production, or enhancement of other resource values (Forest Service Manual 2007). This contrasts with the National Park Service, which permits the ignition of prescribed fires to restore or maintain ecological function if such an objective has been identified by a park (Director's Order #41: Wilderness Stewardship 2013). The National Park Service, which has implemented prescribed burning to restore cultural landscapes in collaboration with Ojibwe partners and the Bureau of Indian Affairs on Stockton Island, part of the Apostle Islands National Lakeshore in Wisconsin, could also consider implementing projects like this within wilderness (as well as expanding to additional parks) while explicitly stating cultural restoration as an objective (U.S. National Park Service 2021).

Proposals to ignite fires within wilderness must confront a number of challenges. Lack of infrastructure such as roads complicates the establishment of fire breaks and access for fire personnel. The remoteness and ruggedness of wilderness areas has prompted managers to propose the use of drones or helicopters for aerial ignitions in lieu of risking crews in dangerous field conditions. However,

wilderness areas have long restricted mechanized equipment and overflights to preserve various wilderness values. Constructing firelines, enhancing natural control lines, and conducting other pre-burn preparations may require special wilderness authorizations, or may need to be achieved without mechanized equipment such as chainsaws. Additionally, working with Tribes to discuss how use of prescribed fire could support their objectives and interests in ancestral lands will necessitate long-term relationship-building (Lake et al. 2017).

Managers have demonstrated that prescribed fire can be successfully implemented within wilderness. In the Boundary Waters Canoe Area Wilderness in Minnesota, over 49,000 acres (20,000 ha) were treated with prescribed fire between 2001 and 2016 (Schwaller et al. 2016), with these treatments significantly lowering fire intensity and severity during the 2006 Cavity Lake Fire and the 2007 Ham Lake Fire. Additionally, areas treated with prescribed fire aided structure protection and burn out operations, and served successfully as fuel breaks which either extinguished the wildfire or benefited suppression efforts (Fites et al. 2007). Currently, a prescribed fire project is treating acres along the Boundary Waters Canoe Area Wilderness boundary, including two burns conducted in 2024. An additional 26,000 acres (11,000 ha) have been proposed for treatment by prescribed fire, with coordination with the Bois Forte Band of Chippewa, Fond du Lac Band of Lake Superior Chippewa, Grand Portage Band of Lake Superior Chippewa, and the 1854 Treaty Authority helping to refine the need for action (Fernberg Corridor Landscape Management Project 2023). In the Scapegoat Wilderness in Montana, a multiyear (2003–2011) prescribed burning effort was able to restore fire to 16,000 acres (6400 ha). While scientific studies of the area are pending, District Ranger Michael Munoz, drawing on 25 years of experience in the Scapegoat Wilderness landscape, observed that several subsequent wildfires were moderated by the previous prescribed burning and required less intervention, including the 2007 Ahorn Fire, 2012 Elbow Complex, and 2021 Dry Cabin Fire (M. A. Munoz, personal communication, February 2, 2024). In the Mission Mountains Wilderness in Montana, over 800 acres (320 ha) were treated with prescribed fire in 2014, with an additional 170 acres (68 ha) treated within the Mission Mountains Wilderness Inventoried Roadless Area (Mission Upland Burning Project 2011). These treated acres served as planned barriers during the 2015 Cedar Peak Fire and the 2016 Piper Fire (A. Du Lac, personal communication, April 3, 2024). In the Sequoia-Kings Canyon Wilderness in California, eighty-four prescribed burns have been conducted across 36,400 acres (14,500 ha) since 1984, the year the area received a wilderness designation (T. Caprio,

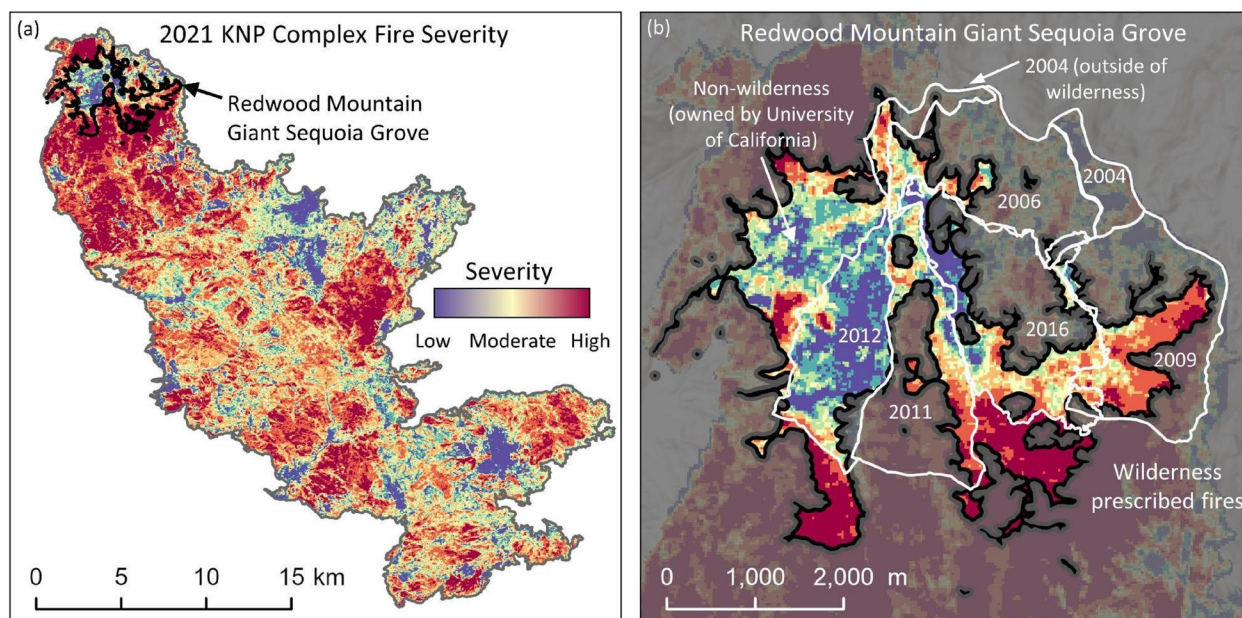


Fig. 4 Maps show the fire severity of the 2021 KNP Complex that primarily occurred within Sequoia-Kings Canyon National Park and Wilderness, California **(a)**. Notably, fire severity in the Redwood Mountain Grove markedly decreased in areas which had been previously treated with prescribed fire **(b)**

personal communication, April 2, 2024). During the 2021 KNP Complex Fire, the Redwood Mountain Giant Sequoia Grove, where some of the earliest prescribed burns were implemented and which became a focus for renewed burning efforts in 2004, experienced markedly reduced fire effects when compared to untreated areas of the grove, as well as other long-unburned groves (see Fig. 4). This is notable given the high rates of mortality in recent years of giant sequoias which experienced high-severity fire (Shive et al. 2022), and which have prompted emergency authorizations for thinning work as well as planned wilderness interventions in the form of planting, discussed in this paper as a fourth order trammel.

In northern California, the Ishi Wilderness provides an example of an emerging collaborative fire stewardship program. The Ishi Wilderness is in a relatively low-elevation area maintained by a frequent fire regime and Indigenous influence. Euro-American settlers forcibly removed and killed the area's Indigenous Yahi-Yana inhabitants in the nineteenth and early twentieth centuries. Wildfires continued to burn within the wilderness until the 1990s. Today, while ecologists and managers recognize the importance of maintaining a frequent fire regime, managing lightning ignitions has been deemed too risky to surrounding communities as a result of infilling of smaller trees caused by three decades of fire suppression (i.e., the second order trammel). This has created a dynamic whereby failure to reintroduce fire in the very near term will increase the likelihood of much

more damaging wildfire (modeled crown fire) in coming decades (i.e., the threat of the third order trammel). Consequently, a partnership group involving surrounding Tribes and Indigenous practitioners has formed to discuss the potential to use prescribed burning and/or Indigenous cultural burning to reduce wildfire risk while preserving values within the Ishi Wilderness, including old-growth trees. An Ishi Wilderness Implementation Plan and Environmental Assessment *from 1989* calls for the use of prescribed fire to reduce unnatural fuel buildups to facilitate the management of lightning-ignited fires, and for a Fire Management Action Plan to be adopted to direct such actions. That plan has yet to be implemented.

In America's wilderness landscapes, federal management agencies have the opportunity to implement prescribed fire in ecosystems which evolved with human- and lightning-ignited fires for thousands of years. In so doing, agencies have both the opportunity, and perhaps the responsibility, to partner with Tribes in rethinking the role of fire stewardship practices in designated wilderness areas. There remain important challenges in designing these efforts to comply with the Wilderness Act's overarching goal of retaining the "natural conditions" of the earth and its community of life, but the active restoration of fire, including human-ignited burning, may be necessary across certain wilderness landscapes to untrammel more than a century of fire exclusion.

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References

- Adlam, C., D. Almandariz, R.W. Goode, D.J. Martinez, and B.R. Middleton. 2022. Keepers of the Flame: Supporting the Revitalization of Indigenous Cultural Burning. *Society & Natural Resources* 35 (5): 575–590. <https://doi.org/10.1080/08941920.2021.2006385>.
- Anderson, M.K., and M.G. Barbour. 2003. Simulated Indigenous Management: A New Model for Ecological Restoration in National Parks. *Ecological Restoration* 21 (4): 269–277. <https://doi.org/10.3368/er.21.4.269>.
- Andrews, C. C. (1900). *Fifth Annual Report of the Chief Fire Warden of Minnesota for the Year 1899*. <https://collection.mndigital.org/catalog/p16022coll11:2197>.
- Aplet, G. H. (2006). Evolution of Wilderness Fire Policy. *International Journal of Wilderness*. https://www.researchgate.net/publication/237127088_Evolution_of_Wilderness_Fire_Policy.
- Berkey, J. K., Miller, C., & Larson, A. J. (2021). A history of wilderness fire management in the Northern Rockies. *Gen. Tech. Rep. RMRS-GTR-428*. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 88 p. <https://doi.org/10.2737/RMRS-GTR-428>.
- Boisramé, G.F.S., S.E. Thompson, C. Tague, and (Naomi), & Stephens, S. L. 2019. Restoring a Natural Fire Regime Alters the Water Balance of a Sierra Nevada Catchment. *Water Resources Research* 55 (7): 5751–5769. <https://doi.org/10.1029/2018WR024098>.
- Bond, W.J., and J.E. Keeley. 2005. Fire as a global “herbivore”: The ecology and evolution of flammable ecosystems. *Trends in Ecology & Evolution* 20 (7): 387–394. <https://doi.org/10.1016/j.tree.2005.04.025>.
- Botti, S., & Nichols, T. (2021). National Park Service fire restoration, policies versus results: What went wrong. *Parks Stewardship Forum*, 37(2). <https://doi.org/10.5070/P537253241>.
- Boyd, R. (1999). *Indians, Fire, and the Land*. Oregon State University Press.
- Calkin, D. E., Thompson, M. P., & Finney, M. A. (2015). *Negative consequences of positive feedbacks in US wildfire management* | SpringerLink. <https://link.springer.com/article/https://doi.org/10.1186/s40663-015-0033-8>.
- Caprio, T. (2024, April 2). *Personal communication* [Email].
- Christianson, A.C., C.R. Sutherland, F. Moola, N. Gonzalez Bautista, D. Young, and H. MacDonald. 2022. Centering Indigenous Voices: The Role of Fire in the Boreal Forest of North America. *Current Forestry Reports* 8 (3): 257–276. <https://doi.org/10.1007/s40725-022-00168-9>.
- Clark, S.A., A. Miller, and D.L. Hankins. 2021. *Good Fire: Current Barriers to the Expansion of Cultural Burning and Prescribed Fire in California and Recommended Solutions*. <https://doi.org/10.13140/RG.2.2.12707.46883>.
- Cocke, A.E., P.Z. Fulé, and J.E. Crouse. 2005. Forest change on a steep mountain gradient after extended fire exclusion: San Francisco Peaks, Arizona, USA. *Journal of Applied Ecology* 42 (5): 814–823. <https://doi.org/10.1111/j.1365-2664.2005.01077.x>.
- Collins, B.M., J.D. Miller, A.E. Thode, M. Kelly, J.W. van Wagtenonk, and S.L. Stephens. 2009. Interactions among wildland fires in a long-established Sierra Nevada natural fire area. *Ecosystems* 12: 114–128.
- Coop, J.D. 2023. Postfire futures in southwestern forests: Climate and landscape influences on trajectories of recovery and conversion. *Ecological Applications* 33 (1): e2725. <https://doi.org/10.1002/eap.2725>.
- Coop, J. D., Parks, S. A., Stevens-Rumann, C. S., Crausbay, S. D., Higuera, P. E., Hurteau, M. D., Tepley, A., Whitman, E., Assal, T., Collins, B. M., Davis, K. T., Dobrowski, S., Falk, D. A., Fornwalt, P. J., Fulé, P. Z., Harvey, B. J., Kane, V. R., Littlefield, C. E., Margolis, E. Q., ... Rodman, K. C. (2020). Wildfire-Driven Forest Conversion in Western North American Landscapes. *BioScience*, 70(8), 659–673. <https://doi.org/10.1093/biosci/biaa061>.
- Coppoletta, M., H.D. Safford, B.L. Estes, M.D. Meyer, S.E. Gross, K.E. Merriam, R.J. Butz, and N.A. Molinari. 2019. Fire Regime Alteration in Natural Areas Underscores the Need to Restore a Key Ecological Process. *Natural Areas Journal* 39 (2): 250–263. <https://doi.org/10.3375/043.039.0211>.
- Courter, J. 2021. *Bucks Lake Wilderness Suppression Report*. USDA Forest Service.
- CPL, & ALWRI. (2023). *Prescribed Fire and U.S. Wilderness Areas: Barriers and Opportunities for Wilderness Fire Management in a Time of Change*. Center for Public Lands-Western Colorado University & Aldo Leopold Wilderness Research Institute. https://static1.squarespace.com/static/6140f68713054212b16cb97ft/64f77f36a3a7db4bb6b9626a/1693941559238/Wilderness_Rxfire_Synthesis.pdf.
- Davis, K.T., S.Z. Dobrowski, P.E. Higuera, Z.A. Holden, T.T. Veblen, M.T. Rother, S.A. Parks, A. Sala, and M.P. Maneta. 2019. Wildfires and climate change push low-elevation forests across a critical climate threshold for tree regeneration. *Proceedings of the National Academy of Sciences* 116 (13): 6193–6198. <https://doi.org/10.1073/pnas.1815107116>.
- Davis, K.T., M.D. Robles, K.B. Kemp, P.E. Higuera, T. Chapman, K.L. Metlen, J.L. Peeler, K.C. Rodman, T. Woolley, R.N. Addington, B.J. Buma, C.A. Cansler, M.J. Case, B.M. Collins, J.D. Coop, S.Z. Dobrowski, N.S. Gill, C. Haffey, L.B. Harris, B.J. Harvey, R.D. Haugo, M.D. Hurteau, D. Kulakowski, C.E. Littlefield, L.A. McCauley, N. Povak, K.L. Shive, E. Smith, J.T. Stevens, C.S. Stevens-Rumann, A.H. Taylor, A.J. Tepley, D.J.N. Young, R.A. Andrus, M.A. Battaglia, J.K. Berkey, S.U. Busby, A.R. Carlson, M.E. Chambers, E.K. Dodson, D.C. Donato, W.M. Downing, P.J. Fornwalt, J.S. Halofsky, A. Hoffman, A. Holz, J.M. Iniguez, M.A. Krawchuk, M.R. Kreider, A.J. Larson, G.W. Meigs, J.P. Roccaforte, M.T. Rother, H. Safford, M. Schaedel, J.S. Sibold, M.P. Singleton, M.G. Turner, A.K. Urza, K.D. Clark-Wolf, L. Yocom, J.B. Fontaine, and J.L. Campbell. 2023. Reduced fire severity offers near-term buffer to climate-driven declines in conifer resilience across the western United States. *Proceedings of the National Academy of Sciences*. <https://doi.org/10.1073/pnas.2208120120>.
- Director's Order #41: Wilderness Stewardship*. (2013). National Park Service. https://www.nps.gov/subjects/policy/upload/DO_41_5-13-2013.pdf.
- Endangered Species Status for Lassic Lupine*. (2023, October 5). Federal Register. <https://www.federalregister.gov/documents/2023/10/05/2023-21477/endangered-and-threatened-wildlife-and-plants-endangered-species-status-for-lassic-lupine-and>.

- Eriksen, C. E. & Hankins, D.L. (2014). The Retention, Revival, and Subjugation of Indigenous Fire Knowledge through Agency Fire Fighting in Eastern Australia and California. *Society & Natural Resources*, Vol. 27, Issue 12. <https://doi.org/10.1080/08941920.2014.918226>.
- Feng, S., H. Lu, P. Tian, Y. Xue, J. Lu, M. Tang, and W. Feng. 2020. Analysis of microplastics in a remote region of the Tibetan Plateau: Implications for natural environmental response to human activities. *Science of the Total Environment* 739: 140087. <https://doi.org/10.1016/j.scitotenv.2020.140087>.
- Fernberg Corridor Landscape Management Project*. (2023). [Scoping Report]. Superior National Forest, Eastern Region, USDA Forest Service.
- Fites, J., Reiner, A., Campbell, M., & Taylor, Z. (2007). *Fire Behavior and Effects, Suppression, and Fuel Treatments on the Ham Lake and Cavity Lake Fires*. Superior National Forest, Eastern Region, USDA Forest Service. https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5304950.pdf.
- Forest Service Manual (FSM 2300-Recreation, Wilderness, and Related Resource Management; Chapter 2320 - Wilderness Management)*. (2007). USDA Forest Service. https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fsbdev3_053277.pdf.
- Fowler, C., and E. Konopik. 2007. The History of Fire in the Southern United States. *Human Ecology Review* 14 (2): 165–176.
- Fulé, P.Z., M. Ramos-Gómez, C. Cortés-Montaño, and A.M. Miller. 2011. Fire regime in a Mexican forest under indigenous resource management. *Ecological Applications* 21: 764–775. <https://doi.org/10.1890/10-0523.1>.
- Guiterman, C.H., E.Q. Margolis, C.H. Baisan, D.A. Falk, C.D. Allen, and T.W. Swetnam. 2019. Spatiotemporal variability of human–fire interactions on the Navajo Nation. *Ecosphere* 10 (11): e02932. <https://doi.org/10.1002/ecs2.2932>.
- Guiterman, C. H., Gregg, R. M., Marshall, L. A. E., Beckmann, J. J., van Mantgem, P. J., Falk, D. A., Keeley, J. E., Caprio, A. C., Coop, J. D., Fornwalt, P. J., Haffey, C., Hagmann, R. K., Jackson, S. T., Lynch, A. M., Margolis, E. Q., Marks, C., Meyer, M. D., Safford, H., Syphard, A. D., ... Stevens, J. T. (2022). Vegetation type conversion in the US Southwest: Frontline observations and management responses. *Fire Ecology*, 18(1), 6. <https://doi.org/10.1186/s42408-022-00131-w>.
- Haffey, C., Sisk, T. D., Allen, C. D., Thode, A. E., & Margolis, E. Q. (2018). Limits to Ponderosa Pine Regeneration following Large High-Severity Forest Fires in the United States Southwest. *Fire Ecology*, 14(1), Article 1. <https://doi.org/10.4996/fireecology.140114316>.
- Hagmann, R. K., Hessburg, P. F., Prichard, S. J., Povak, N. A., Brown, P. M., Fulé, P. Z., Keane, R. E., Knapp, E. E., Lydersen, J. M., Metlen, K. L., Reilly, M. J., Sánchez Meador, A. J., Stephens, S. L., Stevens, J. T., Taylor, A. H., Yocom, L. L., Battaglia, M. A., Churchill, D. J., Daniels, L. D., ... Waltz, A. E. M. (2021). Evidence for widespread changes in the structure, composition, and fire regimes of western North American forests. *Ecological Applications*, 31(8), e02431. <https://doi.org/10.1002/eap.2431>.
- Hankins, D. L. 2013. The effects of indigenous prescribed fire on riparian vegetation in central California. *Ecological Processes* 2 (1): 24. <https://doi.org/10.1186/2192-1709-2-24>.
- Hankins, D.L. & Eriksen, C.E. (2013). Indigenous Fire Knowledge Retention: Spatial, Temporal, Gendered. *Gender and Wildfire: Landscapes of Uncertainty*. Routledge. <https://doi.org/10.4324/9781315779508>.
- Hankins, D. (2024, in press). Climate Resilience Through Ecocultural Stewardship. *Proceedings of the National Academy of Science*.
- Heinselman, M. 1965. Vegetation Management in Wilderness Areas and Primitive Parks. *Journal of Forestry*. 63 (6): 440–445.
- Hendlin, Y.H. 2014. From Terra Nullius to Terra Communis: Reconsidering Wild Land in an Era of Conservation and Indigenous Rights. *Environmental Philosophy* 11 (2): 141–174.
- Hessburg, P.F., D.J. Churchill, A.J. Larson, R.D. Haugo, C. Miller, T.A. Spies, M.P. North, N.A. Povak, R.T. Belote, P.H. Singleton, W.L. Gaines, R.E. Keane, G.H. Aplet, S.L. Stephens, P. Morgan, P.A. Bisson, B.E. Rieman, R.B. Salter, and G.H. Reeves. 2015. Restoring fire-prone Inland Pacific landscapes: Seven core principles. *Landscape Ecology* 30 (10): 1805–1835. <https://doi.org/10.1007/s10980-015-0218-0>.
- Hessburg, P., C. Miller, S. Parks, N. Povak, M. North, B. Collins, T. Spies, C. Canisler, M. Battaglia, and C. Skinner. 2019. Climate, environment, and disturbance history govern resilience of Western North American forests. *Frontiers in Ecology and Evolution*. 7: 239. <https://doi.org/10.3389/fevo.2019.00239>. 7, 11770.
- Heyerdahl, E.K., L.B. Brubaker, and J.K. Agee. 2001. Spatial Controls of Historical Fire Regimes: A Multiscale Example from the Interior West. *Usa. Ecology* 82 (3): 660–678. [https://doi.org/10.1890/0012-9658\(2001\)082\[0660:SCOHFR\]2.0.CO;2](https://doi.org/10.1890/0012-9658(2001)082[0660:SCOHFR]2.0.CO;2).
- Heyerdahl, E.K., D. McKenzie, L.D. Daniels, A.E. Hessl, J.S. Littell, and N.J. Mantua. 2008. Climate drivers of regionally synchronous fires in the inland Northwest (1651–1900). *International Journal of Wildland Fire* 17 (1): 40–49. <https://doi.org/10.1071/WF07024>.
- Hi Lo Project*. (2018). [Final Environmental Impact Statement]. Superior National Forest, Eastern Region, USDA Forest Service.
- Hoffman, K.M., S.B. Wickham, W.S. McInnes, and B.M. Starzomski. 2019. Fire Exclusion Destroys Habitats for At-Risk Species in a British Columbia Protected Area. *Fire* 2 (3): 3. <https://doi.org/10.3390/fire2030048>.
- Holden, Z.A., P. Morgan, and J.S. Evans. 2009. A predictive model of burn severity based on 20-year satellite-inferred burn severity data in a large southwestern US wilderness area. *Forest Ecology and Management* 258 (11): 2399–2406. <https://doi.org/10.1016/j.foreco.2009.08.017>.
- Hunter, M. E., Iniguez, J. M., & Farris, C. A. (2014). *Historical and current fire management practices in two wilderness areas in the southwestern United States: The Saguaro Wilderness Area and the Gila-Aldo Leopold Wilderness Complex* (RMRS-GTR-325; p. RMRS-GTR-325). U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. <https://doi.org/10.2737/RMRS-GTR-325>.
- Hurteau, M.D., J.B. Bradford, P.Z. Fulé, A.H. Taylor, and K.L. Martin. 2014. Climate change, fire management, and ecological services in the southwestern US. *Forest Ecology and Management* 327: 280–289. <https://doi.org/10.1016/j.foreco.2013.08.007>.
- Jaffe, M.R., M.R. Kreider, D.L.R. Affleck, P.E. Higuera, C.A. Seielstad, S.A. Parks, and A.J. Larson. 2023. Mesic mixed-conifer forests are resilient to both historical high-severity fire and contemporary reburns in the US Northern Rocky Mountains. *Forest Ecology and Management* 545: 121283. <https://doi.org/10.1016/j.foreco.2023.121283>.
- Keane, R.E., S. Arno, and L.J. Dickinson. 2006. The Complexity of Managing Fire-dependent Ecosystems in Wilderness: Relict Ponderosa Pine in the Bob Marshall Wilderness. *Ecological Restoration* 24 (2): 71–78. <https://doi.org/10.3368/er.24.2.71>.
- Keane, R. E., Ryan, K. C., Veblen, T. T., Allen, C. D., Logan, J., & Hawkes, B. (2002). Cascading effects of fire exclusion in the Rocky Mountain ecosystems: A literature review. *General Technical Report. RMRS-GTR-91. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 24 p., 091.* <https://doi.org/10.2737/RMRS-GTR-91>.
- Keeley, J.E., J.G. Pausas, P.W. Rundel, W.J. Bond, and R.A. Bradstock. 2011. Fire as an evolutionary pressure shaping plant traits. *Trends in Plant Science* 16 (8): 406–411. <https://doi.org/10.1016/j.tplants.2011.04.002>.
- Keifer, M., Stephenson, N. L., & Manley, J. (2000). *Prescribed Fire as the Minimum Tool for Wilderness Forest and Fire Regime Restoration: A Case Study From the Sierra Nevada, California*. 5.
- Keifer, M. (1998). *Fuel load and tree density changes following prescribed fire in the giant sequoia-mixed conifer forest: The first 14 years of fire effects monitoring.* https://talltimbers.org/wp-content/uploads/2014/03/Keifer1998_op.pdf.
- Kilgore, B. M. (1972). The Role of Fire in a Giant Sequoia-Mixed Conifer Forest. *Research in the Parks: NPS Symposium Series No. 1.* <http://npshistory.com/series/symposia/1/chap6.htm>.
- Kilgore, B. M. (1985). *What is "Natural" in Wilderness Fire Management?* (pp. 57–55). Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture..
- Kilgore, B. M. (1987). *The Role of Fire in Wilderness: A State-of-Knowledge Review* (Proceedings – National Wilderness Research Conference) [General Technical Report].
- Kimmerer, R., and F. Lake. 2001. Maintaining the Mosaic: The role of indigenous burning in land management. *Journal of Forestry* 99: 36–41.
- Kipfmüller, K.F., E.R. Larson, L.B. Johnson, and E.A. Schneider. 2021. Human augmentation of historical red pine fire regimes in the Boundary Waters Canoe Area Wilderness. *Ecosphere* 12 (7): e03673. <https://doi.org/10.1002/ecs2.3673>.
- Knight, C.A., L. Anderson, M.J. Bunting, M. Champagne, R.M. Clayburn, J.N. Crawford, A. Klimaszewski-Patterson, E.E. Knapp, F.K. Lake, S.A. Mensing, D. Wahl, J. Wanket, A. Watts-Tobin, M.D. Potts, and J.J. Battles. 2022. Land management explains major trends in forest structure and composition over the last millennium in California's Klamath Mountains. *Proceedings*

- of the National Academy of Sciences 119 (12): e2116264119. <https://doi.org/10.1073/pnas.2116264119>.
- Kolden, C. A. (2019). We're Not Doing Enough Prescribed Fire in the Western United States to Mitigate Wildfire Risk. *Fire*, 2(2), Article 2. <https://doi.org/10.3390/fire2020030>.
- Kosek, J. (2006). "Smokey Bear Is a White Racist Pig." In *Understories: The Political Life of Forests in Northern New Mexico*. <https://read.dukeupress.edu/books/book/1083/chapter/152429/Smokey-Bear-Is-a-White-Racist-Pig>.
- Kreider, M.R., M.R. Jaffe, J.K. Berkey, S.A. Parks, and A.J. Larson. 2023. The scientific value of fire in wilderness. *Fire Ecology* 19 (1): 36. <https://doi.org/10.1186/s42408-023-00195-2>.
- Kreider, M.R., P.E. Higuera, S.A. Parks, W.L. Rice, N. White, and A.J. Larson. 2024. Fire suppression makes wildfires more severe and accentuates impacts of climate change and fuel accumulation. *Nature Communications* 15 (1): 2412. <https://doi.org/10.1038/s41467-024-46702-0>.
- Du Lac, A. (2024, April 3). *Personal communication* [Email].
- Lake, F.K., V. Wright, P. Morgan, M. McFadden, D. McWethy, and C. Stevens-Rumann. 2017. Returning Fire to the Land: Celebrating Traditional Knowledge and Fire. *Journal of Forestry* 115 (5): 343–353. <https://doi.org/10.5849/jof.2016-043R2>.
- Landres, P., Barns, C., Boutcher, S., Devine, T., Dratch, P., Lindholm, A., Merigliano, L., Roeper, N., & Simpson, E. (2015). Keeping it wild 2: An updated interagency strategy to monitor trends in wilderness character across the National Wilderness Preservation System. *Gen. Tech. Rep. RMRS-GTR-340*. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 114 p., 340. <https://doi.org/10.2737/RMRS-GTR-340>.
- Larson, A.J., R.T. Belote, C.A. Cansler, S.A. Parks, and M.S. Dietz. 2013. Latent resilience in ponderosa pine forest: Effects of resumed frequent fire. *Ecological Applications* 23 (6): 1243–1249. <https://doi.org/10.1890/13-0066.1>.
- Larson, E.R., K.F. Kipfmuller, and L.B. Johnson. 2021. People, Fire, and Pine: Linking Human Agency and Landscape in the Boundary Waters Canoe Area Wilderness and Beyond. *Annals of the American Association of Geographers* 111 (1): 1–25. <https://doi.org/10.1080/24694452.2020.1768042>.
- Lee, H., Calvin, K., Dasgupta, D., Krinner, G., Mukherji, A., Thorne, P. W., Trisos, C., Romero, J., Aldunce, P., Barrett, K., Blanco, G., Cheung, W. W. L., Connors, S., Denton, F., Diongue-Niang, A., Dodman, D., Garschagen, M., Geden, O., Hayward, B., . . . Péan, C. (2023). *IPCC, 2023: Climate Change 2023: Synthesis Report* (First). Intergovernmental Panel on Climate Change (IPCC). <https://doi.org/10.59327/IPCC/AR6-9789291691647>.
- Leopold, A.S., Cain, S.A., Cottam, C.M., Gabrielson, I.N., & Kimball, T.L. (1963). "Wildlife Management in the National Parks." https://www.nps.gov/parkhistory/online_books/leopold/leopold.htm.
- Lewis, H. T. (1973). *Patterns of Indian Burning in California: Ecology and Ethnohistory*. Ballena Press.
- Lieberman, L., B. Hahn, and P. Landres. 2018. Manipulating the wild: A survey of restoration and management interventions in U.S. wilderness. *Restoration Ecology* 26 (5): 900–908. <https://doi.org/10.1111/rec.12670>.
- Long, E., and E. Biber. 2014. The Wilderness Act and Climate Change Adaptation. *Environmental Law* 44: 623–690.
- Long, J.W., F.K. Lake, and R.W. Goode. 2021. The importance of Indigenous cultural burning in forested regions of the Pacific West, USA. *Forest Ecology and Management* 500: 119597. <https://doi.org/10.1016/j.foreco.2021.119597>.
- Long, J.W., F.K. Lake, R.W. Goode, and B.M. Burnette. 2020. How Traditional Tribal Perspectives Influence Ecosystem Restoration. *Ecopsychology* 12: 2. <https://doi.org/10.1089/eco.2019.0055>.
- Lotan, J. E., Kilgore, B. M., Fischer, W. C., & Mutch, R. W. (1983). *Proceedings—Symposium and Workshop on Wilderness Fire* (General Technical Report INT-182). U.S. Forest Service.
- Maclean, K., D.L. Hankins, A.C. Christianson, I. Oliveras, B.A. Bilbao, O. Costello, E.R. Langer, and C.J. Robinson. 2023. Revitalising Indigenous cultural fire practice: Benefits and partnerships. *Trends in Ecology & Evolution* 38 (10): 899–902.
- Marks-Block, T., F.K. Lake, R. Bliege Bird, and L.M. Curran. 2021. Revitalized Karuk and Yurok cultural burning to enhance California hazelnut for basketweaving in northwestern California, USA. *Fire Ecology* 17 (1): 6. <https://doi.org/10.1186/s42408-021-00092-6>.
- Marks-Block, T., and W. Tripp. 2021. Facilitating Prescribed Fire in Northern California through Indigenous Governance and Interagency Partnerships. *Fire* 4 (3): 3. <https://doi.org/10.3390/fire4030037>.
- Metlen, K.L., C.N. Skinner, D.R. Olson, C. Nichols, and D. Borgias. 2018. Regional and local controls on historical fire regimes of dry forests and woodlands in the Rogue River Basin, Oregon, USA. *Forest Ecology and Management* 430: 43–58. <https://doi.org/10.1016/j.foreco.2018.07.010>.
- Miller, C., and G.H. Aplet. 2016. Progress in Wilderness Fire Science: Embracing Complexity. *Journal of Forestry* 114 (3): 373–383. <https://doi.org/10.5849/jof.15-008>.
- Miller, C. (2006). Wilderness fire management in a changing world. *International Journal of Wilderness* 12. https://www.fs.usda.gov/rm/pubs_other/rmrs_2006_miller_c002.pdf.
- Miller, R. 2020. Prescribed Burns in California: A Historical Case Study of the Integration of Scientific Research and Policy. *Fire* 3 (3): 3. <https://doi.org/10.3390/fire3030044>.
- Minor, J., and G.A. Boyce. 2018. Smokey Bear and the pyropolitics of United States forest governance. *Political Geography* 62: 79–93. <https://doi.org/10.1016/j.polgeo.2017.10.005>.
- Mission Upland Burning Project. 2011. *Flathead National Forest*. USDA Forest Service.
- Mistry, J., and A. Berardi. 2016. Bridging indigenous and scientific knowledge. *Science* 352 (6291): 1274–1275. <https://doi.org/10.1126/science.aaf1160>.
- Munoz, M. A. (2024, February 2). *Personal communication* [Email].
- Nie, M. 2008. The Use of Co-Management and Protected Land-Use Designations to Protect Tribal Cultural Resources and Reserved Treaty Rights on Federal Lands. *Natural Resources Journal* 48: 585–647. <https://paperity.org/p/83714158/the-use-of-co-management-and-protected-land-use-designations-to-protect-tribal-cultural>.
- Norgaard, K. M., & Tripp, W. (2019). *Karuk Climate Adaptation Plan*. Karuk Tribe. https://www.karuk.us/images/docs/dnr/FINAL%20KARUK%20CLIMATE%20ADAPTATION%20PLAN_July2019.pdf.
- North, M.P., S.L. Stephens, J.K. Agee, G.H. Aplet, J.F. Franklin, and P.Z. Fule. 2015. Reform forest fire management. *Science* 349 (6254): 1280–1281. <https://doi.org/10.1126/science.aab2356>.
- North, M.P., S.M. Bisbing, D.L. Hankins, P.F. Hessburg, M.D. Hurteau, L.N. Kobziar, M.D. Meyer, A. Rhea, S.L. Stephens, and C.S. Stevens-Rumann. (2024). Strategic Fire Zones: A Crucial Addition to Western US Wildfire Risk Reduction. *Fire Ecology*.
- Nowacki, G.J., and M.D. Abrams. 2008. The demise of fire and "mesophication" of forests in the eastern United States. *BioScience*. 58 (2): 123–138. <https://doi.org/10.1641/b580207>.
- Ortega-Welch, M. (Director). (2023, July 24). Untrammled: How a plan to replant giant sequoias unearths questions about the meaning of wilderness. In *KALW*. <https://www.kalw.org/2023-07-24/untrammled-how-a-plan-to-replant-giant-sequoias-unearts-questions-about-the-meaning-of-wilderness>.
- Parks, S.A., C. Miller, C.R. Nelson, and Z.A. Holden. 2014. Previous Fires Moderate Burn Severity of Subsequent Wildland Fires in Two Large Western US Wilderness Areas. *Ecosystems* 17 (1): 29–42. <https://doi.org/10.1007/s10021-013-9704-x>.
- Parks, S.A., M.-A. Parisien, C. Miller, L.M. Holsinger, and L.S. Baggett. 2018. Fine-scale spatial climate variation and drought mediate the likelihood of reburning. *Ecological Applications* 28 (2): 573–586. <https://doi.org/10.1002/eap.1671>.
- Parks, S.A., L.M. Holsinger, K. Blankenship, G.K. Dillon, S.A. Goeking, and R. Swaty. 2023. Contemporary wildfires are more severe compared to the historical reference period in western US dry conifer forests. *Forest Ecology and Management* 544: 121232. <https://doi.org/10.1016/j.foreco.2023.121232>.
- Parks, S. A., Dobrowski, S., Shaw, J. D., & Miller, C. (2019). Living on the edge: Trailing edge forests at risk of fire-facilitated conversion to non-forest. *Ecosphere* 3. <https://doi.org/10.1002/ecs2.2651>.
- Parsons, D.J., D.M. Graber, J.K. Agee, and J.W. Van Wagtenonk. 1986. Natural fire management in National Parks. *Environmental Management* 10 (1): 21–24. <https://doi.org/10.1007/BF01866414>.
- Parsons, D. J. (2000). The challenge of restoring natural fire to wilderness. In: *Cole, David N.; McCool, Stephen F.; Borrie, William T.; O'Loughlin, Jennifer, Comps. 2000. Wilderness Science in a Time of Change Conference-Volume 5: Wilderness Ecosystems, Threats, and Management; 1999 May 23–27; Missoula, MT. Proceedings RMRS-P-15-VOL-5*. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 276–282, 015. <https://www.fs.usda.gov/research/treearch/21874>.

- Prichard, S.J., P.F. Hessburg, R.K. Hagmann, N.A. Povak, S.Z. Dobrowski, M.D. Hurteau, V.R. Kane, R.E. Keane, L.N. Kobziar, C.A. Kolden, M. North, S.A. Parks, H.D. Safford, J.T. Stevens, L.L. Yocom, D.J. Churchill, R.W. Gray, D.W. Huffman, F.K. Lake, and P. Khatri-Chhetri. 2021. Adapting western North American forests to climate change and wildfires: 10 common questions. *Ecological Applications* 31 (8): e02433. <https://doi.org/10.1002/eap.2433>.
- Roos, C. I., Guiterman, C. H., Margolis, E. Q., Swetnam, T. W., Laluk, N. C., Thompson, K. F., Toya, C., Farris, C. A., Fulé, P. Z., Iniguez, J. M., Kaib, J. M., O'Connor, C. D., & Whitehair, L. (2022). Indigenous fire management and cross-scale fire-climate relationships in the Southwest United States from 1500 to 1900 CE. *Science Advances* 8(49). <https://doi.org/10.1126/sciadv.abq3221>.
- Roos, C. I., Swetnam, T. W., & Guiterman, C. H. (2023). Indigenous Land Use and Fire Resilience of Southwest USA Ponderosa Pine Forests. In *Climatic and Ecological Change in the Americas*. Routledge.
- Ryan, K.C., Jones, A. T., Koerner, C.L., & Lee, K.M. (2012). Wildland Fire in Ecosystems: Effects of Fire on Cultural Resources and Archaeology. *General Technical Report*. Rocky Mountain Research Station, USDA Forest Service. https://www.fs.usda.gov/rm/pubs/rmrs_gtr042_3.pdf.
- Schoennagel, T., T.T. Veblen, and W.H. Romme. 2004. The Interaction of Fire, Fuels, and Climate across Rocky Mountain Forests. *BioScience* 54 (7): 661–676. [https://doi.org/10.1641/0006-3568\(2004\)054\[0661:TIOFFA\]2.0.CO;2](https://doi.org/10.1641/0006-3568(2004)054[0661:TIOFFA]2.0.CO;2).
- Schwaller, A., Creighton, E., Anderson, T., Wickman, T., Johnson, L., Jenkins, B., & Johnson, P. (2016). *Boundary Waters Canoe Area Wilderness Fuel Treatment Final Environmental Impact Statement* [Supplemental Information Report]. Superior National Forest, Eastern Region, USDA Forest Service.
- Seielstad, C. (2015). Reconsidering wildland fire use: Perspectives from the Northern Rockies. In: *Keane, Robert E.; Jolly, Matt; Parsons, Russell; Riley, Karin. Proceedings of the Large Wildland Fires Conference; May 19–23, 2014; Missoula, MT. Proc. RMRS-P-73. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 207–212, 73, 207–212.*
- Sherriff, R.L., R.V. Platt, T.T. Veblen, T.L. Schoennagel, and M.H. Gartner. 2014. Historical, Observed, and Modeled Wildfire Severity in Montane Forests of the Colorado Front Range. *PLoS ONE* 9 (9): e106971. <https://doi.org/10.1371/journal.pone.0106971>.
- Shive, K.L., A. Wuenschel, L.J. Hardlund, S. Morris, M.D. Meyer, and S.M. Hood. 2022. Ancient trees and modern wildfires: Declining resilience to wildfire in the highly fire-adapted giant sequoia. *Forest Ecology and Management* 511: 120110. <https://doi.org/10.1016/j.foreco.2022.120110>.
- Skinner, C.N., C.S. Abbott, D.L. Fry, S.L. Stephens, A.H. Taylor, and V. Trouet. 2009. Human and Climatic Influences on Fire Occurrence in California's North Coast Range, USA. *Fire Ecology* 5 (3): 76–99. <https://doi.org/10.4996/fireecology.0503076>.
- Speck, O., & Speck, T. (2024). Is a Forest Fire a Natural Disaster? Investigating the Fire Tolerance of Various Tree Species—An Educational Module. *Biomimetics*, 9(2), Article 2. <https://doi.org/10.3390/biomimetics9020114>.
- Spence, M. D. (1999). *Dispossessing the Wilderness: Indian Removal and the Making of the National Parks*. Oxford University Press.
- Stan, Amanda B., Peter Z. Fulé, Kathryn B. Ireland, and Jamie S. Sanderlin. 2014. Modern fire regime resembles historical fire regime in a ponderosa pine forest on Native American lands. *International Journal of Wildland Fire* 23: 686–697. <https://doi.org/10.1071/WF13089>.
- Stephens, S.L., S. Thompson, G. Boisramé, B.M. Collins, L.C. Ponisio, E. Rakhmatulina, Z.L. Steel, J.T. Stevens, J.W. van Wagtenonk, and K. Wilkin. 2021. Fire, water, and biodiversity in the Sierra Nevada: A possible triple win. *Environmental Research Communications* 3 (8): 081004.
- Stephenson, N., & Brigham, C. (2021). *Preliminary estimates of sequoia mortality in the 2020 Castle Fire* [National Park Service Report].
- Stevens-Rumann, C.S., K.B. Kemp, P.E. Higuera, B.J. Harvey, M.T. Rother, D.C. Donato, P. Morgan, and T.T. Veblen. 2018. Evidence for declining forest resilience to wildfires under climate change. *Ecology Letters* 21 (2): 243–252. <https://doi.org/10.1111/ele.12889>.
- Stewart, O. C. (2002). *Forgotten Fires: Native Americans and the Transient Wilderness*. University of Oklahoma Press.
- Swetnam, T.W., J. Farella, C.I. Roos, M.J. Liebmann, D.A. Falk, and C.D. Allen. 2016. Multiscale perspectives of fire, climate and humans in western North America and the Jemez Mountains, USA. *Philosophical Transactions of the Royal Society B: Biological Sciences* 371 (1696): 20150168. <https://doi.org/10.1098/rstb.2015.0168>.
- Taylor, A.H., V. Trouet, C.N. Skinner, and S. Stephens. 2016. Socioecological transitions trigger fire regime shifts and modulate fire–climate interactions in the Sierra Nevada, USA, 1600–2015 CE. *Proceedings of the National Academy of Sciences* 113 (48): 13684–13689. <https://doi.org/10.1073/pnas.1609775113>.
- The Wildland Research Center, and U. of C. 1962. *Wilderness and Recreation, A Report on Resources, Values, and Problems: Report to the Outdoor Recreation Resources Review Commission by the Wildland Research Center*. Government Printing Office: University of California. U.S.
- Thompson, J. C., Wright, D. K., Ivory, S. J., Choi, J.-H., Nightingale, S., Mackay, A., Schilt, F., Otárola-Castillo, E., Mercader, J., Forman, S. L., Pietsch, T., Cohen, A. S., Arrowsmith, J. R., Welling, M., Davis, J., Schiery, B., Kaliba, P., Malijani, O., Blome, M. W., ... Gomani-Chindebvu, E. (2021). Early human impacts and ecosystem reorganization in southern-central Africa. *Science Advances* 7(19): eabf9776. <https://doi.org/10.1126/sciadv.abf9776>.
- U.S. National Park Service. (2021). *Stockton Island Prescribed Burn Restores Cultural Landscapes*. <https://www.nps.gov/articles/000/stockton-island-prescribed-burn-restores-cultural-landscapes.htm>.
- Vinyeta, K. 2022. Under the guise of science: How the US Forest Service deployed settler colonial and racist logics to advance an unsubstantiated fire suppression agenda. *Environmental Sociology* 8 (2): 134–148. <https://doi.org/10.1080/23251042.2021.1987608>.
- van Wagtenonk, J.W. 2007. The History and Evolution of Wildland Fire Use. *Fire Ecology* 3 (2): 2. <https://doi.org/10.4996/fireecology.0302003>.
- Walker, R. B., Coop, J. D., Parks, S. A., & Trader, L. (2018). Fire regimes approaching historic norms reduce wildfire-facilitated conversion from forest to non-forest. *Ecosphere* 9(4). <https://doi.org/10.1002/ecs2.2182>.
- Watson, A., Matt, R., Knotek, K., Williams, D. R., & Yung, L. (2011). Traditional Wisdom: Protecting Relationships with Wilderness as a Cultural Landscape. *Ecology and Society* 16(1). <https://www.jstor.org/stable/26268851>.
- "Wilderness Agencies" Wilderness Connect. <https://wilderness.net/learn-about-wilderness/agencies.php>.
- Williams, J.N., H.D. Safford, N. Enstice, Z.L. Steel, and A.K. Paulson. 2023. High-severity burned area and proportion exceed historic conditions in Sierra Nevada, California, and adjacent ranges. *Ecosphere* 14 (1): e4397. <https://doi.org/10.1002/ecs2.4397>.
- Yung, L. (2008). *Prescribed Fires in Wilderness—Case Study*. <https://www.umt.edu/media/wilderness/toolboxes/documents/fire/Prescribed%20Fires%20in%20Wilderness%20-%20case%20study.pdf>.

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