CONTRIBUTED PAPER

Protecting restoration investments from the cheatgrass-fire cycle in sagebrush steppe

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Abstract
The U.S. federal government has recently committed to the difficult task of slowing and managing the invasive grass-fire cycle in sagebrush steppe, where property, livelihoods, and entire ecosystems are at risk. To safely manage this crisis, the government recently proposed to construct about 17,700 km of fuel breaks and millions of hectares of fuel reduction treatments in six western states. A challenge for resource managers will be the strategic placement of these land treatments. We investigated the need for this massive effort from the perspective of protecting previous rehabilitation and restoration seeding investments, including over 3,400 seedings implemented from 1990 to 2019 covering about 24,540 km². We found that portions of over 26% of these seedings have since burned representing nearly 17% of this seeded area. Locations that had recurrent wildfire had repeat treatments and thus multiple investments in the same location. Our analysis supports the management actions aimed at protecting remaining sagebrush and restoration investments, especially in areas where the invasive grass-fire cycle is most pervasive. Given the decades required for most sagebrush to recover after wildfire, the urgency of this management intervention is evident. The specific details, placement, and effectiveness of these interventions could influence outcomes and potential unintended consequences.

KEYWORDS
Bromus tectorum, fuel break, fuel treatment, network, rehabilitation, sage-grouse, shrubland

1 | INTRODUCTION

In the western United States, one of the largest shrub steppe ecosystems in the world is at risk because of larger and more frequent wildfires than occurred historically (Chambers et al., 2017). The new fire regime is primarily caused by invasive, annual grasses (particularly cheatgrass, Bromus tectorum) that have changed fuel compositions such that fires are able to spread more easily and reburn more frequently (Balch, Bradley, D’Antonio, & Gómez-Dans, 2013; Pilliod, Welty, & Arkle, 2017). This novel grass-fire cycle eventually eliminates long-lived, foundational shrub species, like sagebrush (Artemisia spp.), which suffer high mortality during fire, and have low seed viability in soils (Davies et al., 2012; Ellsworth, Kauffman, Reis,
Sapsis, & Moseley, 2020; Mahood & Balch, 2019). The result has been a rapid loss of sagebrush steppe communities immediately after fire as well as a steady loss of sagebrush communities over longer timeframes (i.e., decades) because of a lack of seed sources, degraded soils, competition with non-native species, unsuitable climate conditions, and recurrent wildfire that limit germination and establishment (Schlaepfer, Lauenroth, & Bradford, 2014; Shriver et al., 2018). Given these frequent pulse- and unsustainable press-disturbances in sagebrush steppe, the need for effective intervention to conserve these plant communities is increasingly critical (Chambers et al., 2017; Davies et al., 2011).

Sagebrush (Artemisia spp.) ecosystems in North America gained conservation attention over the last several decades, primarily because of the threat wildfires pose to wildlife species and working rangelands. The Greater Sage-grouse (Centrocercus urophasianus) is the flagship species for sagebrush ecosystems because it requires vast areas of sagebrush and it is a popular game species whose populations have declined considerably in many areas (Coates et al., 2016; Garton et al., 2011). Other sagebrush-associated inhabitants of this cold desert biome have also experienced population declines and are at risk of extirpation, largely due to conversion of sagebrush shrublands to invasive annual grasslands (Knick et al., 2003; Rottler, Noseworthy, Fowers, & Beck, 2015).

In response to the decline of sagebrush-dependent species and impacts to rural economies, local, state, and federal governments have worked independently and partnered with private landowners and non-profit organizations to find ways to slow and reverse the cheatgrass-fire problem (Chambers, Beck, et al., 2017; Knick, 2011). A paradigm shift occurred in 2015 when the US Department of Interior (DOI) introduced a comprehensive fire prevention, management, and restoration strategy (Secretarial Order 3336) for sagebrush landscapes across the West, particularly the Great Basin. This strategy focused on protecting, conserving, and restoring the health of sagebrush steppe, and Greater Sage-grouse habitat, in particular, through strategic allocation of fire management resources (before, during, and after wildfire) and restoration investments. Postfire restoration activities included planting grasses, forbs, and sagebrush immediately following fires to assist plant community recovery, converting cheatgrass-dominated areas to more fire-resistant and resilient native plant communities, and removing juniper trees that had expanded into sagebrush shrublands, reducing habitat quality for Greater Sage-grouse. The aim of this concerted effort was to protect remaining areas of uninvaded sagebrush, where disturbance is relatively minor or infrequent (often called “healthy” or “intact” rangelands), to reduce wildfire spread in areas with at least some sagebrush (even if previously invaded), and to restore areas that had been disturbed or degraded by wildfires, weeds, or intensive land uses.

Prefire fuel management, active wildfire suppression, and postfire restoration of rangelands are all expensive activities. The Department of Interior’s Bureau of Land Management (BLM), for example, oversees approximately 700 thousand km² (172.9 M acres) across the contiguous 48 states, about 14.7% of the total land area of the conterminous United States. Suppressing wildfires on BLM-administered lands in Utah, Nevada, and Idaho alone, cost taxpayers more than $373 M dollars between 2009 and 2018 (BLM, 2020b). Prefire fuel reduction and postfire restoration costs are also in the millions of dollars annually. For example, over the last decade, the BLM spent an average of about $21 M per year rehabilitating burned areas through actions such as seeding, herbicide applications, soil stabilization, and closures (BLM, 2020b). Portions of these funds enabled BLM to seed nearly 13,600 km² (3.4 M acres) between 2010 and 2019 (Pilliod, Welty, & Jeffries, 2019), in part with the intent of restoring sage-grouse habitat in the Great Basin (Pilliod, Welty, & Toevs, 2017). The Sage Grouse Initiative (SGI), a public-private partnership led by US Department of Agriculture’s Natural Resources Conservation Service (NRCS), spent over $30 M in 2018 on habitat conservation and improvement projects aimed at conserving at-risk wildlife in western rangelands (USDA-NRCS, 2018). Since 2010, with help from the Farm Bill, SGI has conserved or actively managed habitat for wildlife on more than 28,328 km² (7 M acres) of private ranchlands across 11 western states.

Cheatgrass invasions and wildfire threaten these rehabilitation and restoration investments, and remaining sagebrush habitats (Epanchin-Niell, Englin, & Nalle, 2009). In 2020, for example, an additional 12,702 km² (3.14 M acres) burned within sagebrush ecosystems (Jeffries & Finn, 2019; National Interagency Fire Center, 2021). Re-establishing recently burned sagebrush is unlikely in many locations for reasons previously stated. Even where successful, it can take over 20–30 years to achieve the height and cover required for many wildlife species (Arkle et al., 2014; Cooper, Lesica, & Kudray, 2011; Knutson et al., 2014; Lesica, Cooper, & Kudray, 2007; Mata-González, Reed-Dustin, & Rodhouse, 2018; Nelson, Weisberg, & Kitchen, 2014; Shinneman & McIlroy, 2016; Shriver et al., 2018). Hence, every reburning resets an area’s recovery trajectory and makes recovery less likely. The challenge is how to protect these restoration investments, at least until plant communities have reached a desired state to provide a sought-after ecosystem service.

In April 2020, DOI attempted to address this challenge by developing a plan for the construction and maintenance of a massive, mainly linear, fuel break network spanning
17,703 km (11,000 miles) within a 902,450 km² (223 M acres) area in portions of California, Idaho, Nevada, Oregon, Utah, and Washington (Figure 1; BLM, 2020a). Federal law mandated a formal review process under the National Environmental Policy Act (NEPA) resulting in publication of the Final Programmatic Environmental Impact Statement for Fuel Breaks in the Great Basin (hereafter, PEIS). A second PEIS was developed for the same analysis area that outlines fuel reduction and rangeland restoration projects, including authorizing treatments on up to 153,781 km² (38 M acres; BLM, 2021). The intent of the fuel breaks and fuel treatments is to redistribute, reduce, or remove biomass using a combination of herbicide applications, targeted grazing, and mechanical methods, such as mowing, chaining, mastication, and thinning. The goal of these treatments is to interrupt the continuity of the fuels, thus helping fire managers engage in suppression to reduce the spread and size of wildfires (see panels a and b in Figure 1 for the scale of this issue). Many of these fuel breaks and fuel treatments will be placed along existing roads and right of ways to maximize effectiveness and fire fighter access and safety (Oliveira, Barros, Ager, & Fernandes, 2016). But these potential benefits are not without potential costs, including the fragmentation of remaining sagebrush habitats and restoration investments they are intended to protect (Shinneman et al., 2019).

The BLM recognized those concerns and has proposed solutions we discuss later in this article (BLM, 2020a). Here, we examine the need for this unprecedented fuels treatment network from the perspective of protecting existing restoration investments in areas identified as priorities under the Department of Interior’s 2020 Fuels Reduction and Rangeland Restoration Initiative. Specifically, we assess the proportion of land area within BLM’s PEIS treatment analysis area (BLM, 2021) that has received restoration seeding treatments from 1990 to 2019, and then subsequently burned. We were particularly interested in quantifying potential gains (i.e., areas seeded that remain intact) versus losses (i.e., areas burned, including previously seeded areas) through time and across the region, to identify critical areas where slowing the fire cycle might be prioritized. This assessment provides a scientific basis for evaluating both the need for, and the future effectiveness of, these landscape-level management decisions as they are implemented across the region over the next several years. We provide the first assessment of the magnitude of this conservation challenge and examine where these landscape efforts might need to be concentrated for success.

2 | METHODS

We first compiled all seeding treatments implemented from 1990 to 2019 within the PEIS treatment analysis area (Figure 1) that were present in the Land Treatment Digital Library, a geodatabase of all available, historic management actions influencing vegetation and soils on public lands administered by the BLM (Pilliod et al., 2019). We intersected those seeding treatments with wildfire boundaries (Welty & Jeffries, 2020) using ArcGIS Pro Software (ESRI, Redlands, CA) and identified wildfires that occurred before and after each treatment. Finally, we quantified the area of each treatment that subsequently burned after seeding.

For each seeding, we calculated the amount and proportion of seeded area that burned each year and the years between seeding treatment implementation and each subsequent wildfire. We removed instances where less than 1% of the seeded area burned in an attempt to avoid or reduce geospatial errors. We calculated these summary statistics at three levels of detail. First, we calculated these variables for each independent burning event, regardless of whether subsequent wildfires burned over the same area of the seeding. In other words, seeded treatments that burned multiple times were summarized for each separate burn event. Additionally, if seedings overlapped, the subsequent wildfire events that burned over both were counted independently. This level of detail allows for analysis of each wildfire event for each seeding. Second, we calculated the portion of each seeding that was intact after any fire (through 2019) that occurred after the implementation of the seeding investment. This allowed us to evaluate the total area of the seeding that remained intact for each individual seeding. Thus, for these first spatial analyses, each seeding investment is treated as an independent sample, even if some overlap. In contrast, our last analysis evaluated the total land area of treatments burned, regardless of overlapping treatments, by combining and dissolving: (a) all seeding treatment areas that had never burned in wildfires and (b) all seeding treatment area that had subsequently burned in wildfires. We define land area as the surface area of the land of a geographical extent. Thus, these two features allowed us to report the amount of seeded land area that remained (i.e., was still intact) compared with the amount of seeded land area that had burned-over at least once in the 30-year period.

The seeding and re-seeding legacy of the analysis area is complicated (Pilliod, Welty, & Toevs, 2017) and required us to create a careful record of the spatial overlap and temporal timing of both seedings and wildfires. As previously mentioned, some areas received multiple seedings (e.g., aerial seeding overlapping a drill seeding) prior to the first wildfire in our 30-year period. In total, we found 135 “re-seeding” events at 83 locations that were conducted before the first wildfire occurred and for a variety of reasons unrelated to subsequent wildfire, such as failure of the initial seeding attempt or as part of
restoration maintenance. These reseeding efforts covered about 340 km² (84,069 acres) of original seeding area that was reseeded prior to the first wildfire and thus represent a fairly minor component of the dataset. We report it here for full transparency and to point out the spatiotemporal complexities of quantifying restoration and wildfire events in real-world managed landscapes.

We also summarized results by the Natural Resources Conservation Service’s Major Land Resource Areas (MLRA) to provide geographical context (USDA-NRCS, 2020). MLRAs are used by natural resource managers to subdivide land into areas with similar soils, climate, and vegetation or crop types. Details of this analysis are provided in a graphical supplement as a resource for managers to examine the observed patterns at relevant biophysical and administrative scales (https://doi.org/10.5066/P931LUJ1).

3 | RESULTS

We found records of 3,408 seeding treatments that were implemented on BLM-administered lands from 1990 to 2019 and intersect the PEIS treatment analysis area (i.e., analysis area) in whole or in part. First, we report findings for each seeding investment, which allowed for the independent inclusion of overlapping treatments. Of the total seedings that intersected the analysis area, 4.2% burned nearly entirely in subsequent wildfires (>95% of the seeding area burned), 22.4% burned partially, and
73.4% remained mostly intact (i.e., <5% of the treatment area burned) by the end of 2019. The overall area of seedings, including treatments that overlapped, was nearly 35,740 km² (8,831,504 acres; Figure 2). When each wildfire event on each seeding was treated independently, we found that a total of 12,307 km² of subsequent burning events had occurred on seeding investments (3,041,246 acres; Figure 2). When each independent seeding investment was considered, regardless of frequency of burning events, we found that over a quarter (26.3%) of the cumulative area of all past seeding treatments had subsequently burned in wildfires. This cumulative area of burned seedings summed to 9,418 km² (2,327,302 acres). This left 73.7% (26,322 km²; 6,504,202 acres) of the cumulative seeding investment area of all seedings implemented in the previous 30 years unburned by the end of 2019. Given our time-constrained dataset, we confirmed the expected negative relationship between time since a seeding was implemented and the percent of the seeding area that was still intact (Figure 3). Understandably, more recent seedings had fewer opportunities (i.e., years) in which to burn.

Next, we report our findings for total land area, which dissolved overlapping seeding treatment areas with the same fate (i.e., burned or intact seeding). Collectively, across the analysis area, seeding treatments covered a land area of 24,540 km² (6,063,848 acres), approximately the size of New Hampshire. This is less than the 35,740 km² reported in the previous paragraph because some areas received multiple seeding investments in the 30-year period. Overall, we found that just over 4,142 km² (~1,023,592 acres) or 16.9% of land area previously seeded has since burned during the 30 years prior to 2019, whereas 20,397 km² (5,040,256 acres) or 83.1% of land area seeded remains intact.

Considering the number of seedings during our period of record that experienced a subsequent burn event, we found evidence that fires are burning too frequently in many locations for sagebrush to recover across an entire seeding area, as the median time between seeding and subsequent wildfire was only 9 years (Figure 4). In those wildfire events, rarely did the entire seeded area burn, however, and the median seeded area burned in any given wildfire was 28.3% (Figure 4). When only sagebrush seedings were considered, we found the median time until fire was about 8.6 years after implementation compared to 9.4 years after implementation for seedings without sagebrush (not shown).

The spatial distribution of restoration seedings and the risk of wildfire to those investments is not uniform across the analysis area. We found that the Owyhee High Plateau MLRA contained the majority of seeded area and the highest proportion of seeded areas that have subsequently burned (Figure 5; also see supporting information at https://doi.org/10.5066/P931LUJ1). The Snake River Plains MLRA had the second greatest area seeded
and second greatest proportion of seeded areas that have burned (Figure 5). Together, these two MLRAs represent greater area seeded, and greater amounts of seeded areas that have subsequently burned in wildfires, than all other MLRAs combined. Three other MLRAs had at least 2,000 km² (~494,000 acres) seeded during our 30-year period of record. When these and other MLRAs were ranked by total area seeded, the percentage of seeded area that has since burned ranged from 2 to 56% within the top 10 MLRAs (Figure 5).

4 | DISCUSSION

Our analysis contributes to a growing body of evidence that support proposed management actions aimed at protecting remaining sagebrush and restoration investments, especially in areas where the invasive grass-fire cycle is most pervasive. Our finding that at least one in four seedings in the analysis area have partially or completely burned in wildfires between 1990 and 2019 is, paradoxically, both discouraging and promising. The loss of investment is staggering, especially because fire tends to kill sagebrush and other fire intolerant perennial species that are planted to stabilize the soils, prevent invasion from non-native plant species, recover habitat for wildlife, and provide forage for livestock. Natural rates of recovery of sagebrush shrublands are slow and unpredictable, sometimes spanning decades, particularly at warmer, drier sites at lower elevations (Chambers, Maestas, et al., 2017). Thus, a single fire event can undo restoration efforts and reset recovery trajectories for sagebrush shrublands (Cooper et al., 2011; Ellsworth et al., 2020; Lesica et al., 2007; Nelson et al., 2014; Shinneman & McIlroy, 2016). In locations where treatments were burned over, the median time between seeding and burning was only 9 years, a fire frequency that is too short to support sagebrush shrubland plant and animal communities. This is discouraging, but the flip side to our findings is that 3 in 4 seedings, and nearly 75% of the seeded area (and 83.1% of the seeded land area), has not burned during the last three decades. Hence, many restoration investments are still intact, and some are on a trajectory of recovery (although other factors, such as weather and drought, also play a role in the rates and likelihood of reaching desired restoration
outcomes; Pyke, 2011; Shriver et al., 2018). This creates an opportunity where fuel breaks could be prioritized in areas where high fire risk and short fire-return intervals overlap with seedings and other high priority resources, such as sage-grouse leks or large stands of intact sagebrush (Ricca & Coates, 2020). Indeed, our findings suggest that most of the cheatgrass-fire cycle problem is currently concentrated in two regions within the PEIS analysis area (i.e., Owyhee High Plateau and Snake River Plain), rather than being widespread. This concentration enables more focused prefire management, suppression, restoration, and perhaps public education and outreach.

The grass-fire cycle is a wicked problem (in the sense of Allen & Gould Jr., 1986) that will require creative solutions, tough decisions, and stakeholder (including public) involvement. Wicked problems have few solutions because of their scale, economic burden, complexity, interconnectedness with many factors, and the plurality of societal values and views about the problem. In other words, wicked problems tend to be managed for best outcomes instead of ultimate solutions (Brunson, 2012). The construction of fuel breaks in sagebrush steppe is not a perfect solution to the grass-fire cycle because these large-scale management actions (up to 182 m, or 600 ft wide, by many km long) may have trade-offs of their own. Recognized trade-offs include saving some intact sagebrush areas while fragmenting or removing others to do so or installing breaks in otherwise continuous fine fuels of annual grasslands while creating a new disturbance that can act as a conduit for cheatgrass invasion into otherwise uninvaded locations (Crist, Chambers, Phillips, Prentice, & Wiechman, 2019; Shinneman et al., 2019). Not trivially, the efficacy of fuel breaks and fuel treatments in sagebrush landscapes, especially in fire-prone landscapes and under extreme fire-weather conditions, is highly uncertain, and the largest amount of area burned in wildfires occurs during extreme fire-weather conditions (Shinneman et al., 2019). A no-action alternative, however, could result in the loss of this iconic ecosystem of the American west, as the rate of sagebrush loss to wildfire is, or will soon be, exceeding the rate of recovery. This sets up a false dichotomy of sorts, however, whereby resource managers either carry out fuels reduction and build fuel breaks, or risk losing the entire resource. In reality, the solution is likely more nuanced and could include reducing human ignitions (Balch et al., 2017), reducing management activities that perpetuate invasive, fire-prone grasses (Reisner, Grace, Pyke, & Doescher, 2013), developing strategic management to reduce or eliminate invasive annual grasses (WGA, 2020), and forecasting where these risks are greatest (Chambers et al., 2019). New products like the Rangelands Analysis Platform (https://rangelands.app/cheatgrass; Jones et al., 2020) and USGS's near-real-time herbaceous annual cover data (Boyte, Wylie, & Major, 2019) will greatly aid these endeavors. Regardless, spending resources to protect intact sagebrush stands and to protect previous investments through fuel

**FIGURE 4** Density scatterplot of the years between seeding implementation and all subsequent burning events (x-axis) and the percent of the seeded area that was burned for each burning event (y-axis). The data distributions are shown as histograms for each axis.
management and fire suppression appear to be an important part of this solution (Epanchin-Niell et al., 2009).

Rangeland managers in the western United States, particularly at public natural resource agencies, are well aware of the wildfire-prevention/suppression conundrum and the challenges associated with taking action to manage wildfire. The BLM recognized concerns that creating a fuel break network of this scale could result in loss and fragmentation of sagebrush habitats and serve as a conduit for the spread of invasive weeds (Shinneman et al., 2019). In response to these concerns, the BLM proposed to place fuel breaks in already fragmented areas, such as along roads and rights of ways, and in manners that minimize impacts to intact sagebrush communities, yet maximize fuel break effectiveness (BLM, 2020a; BLM, 2021). The BLM also proposed to integrate fuel break maintenance and the treatment of noxious weeds into its planning to improve effectiveness of new and existing fuel breaks and reduce the spread of invasive weeds. It is possible that these plans may evolve and management will adapt as new science becomes available.

Besides identifying and quantifying the need for protection of prior restoration investments in this ecosystem, this analysis can also provide a baseline risk assessment of actual loss of investments to the grass-fire cycle. This baseline is important because the cheatgrass-fire cycle risk is not static and future analyses will need to consider how this risk may change in relation to spatial and temporal variation in invasive annuals and herbaceous fuels. Ideally this information could aid real-time decision making about fuel management and suppression in a geographic context, such as at a useful administrative (e.g., field office or district) or MLRA scale. Our findings were mostly consistent with analyses of wildfire patterns in the western United States that found that most of the wildfire problem on non-forested lands was concentrated in the northern Great Basin (Brooks, Matchett, Shinneman, & Coates, 2015; Dennison, Brewer, Arnold, & Moritz, 2014; Pilliod, Welty, & Arkle, 2017). Brooks et al. (2015) also concluded that the cheatgrass-fire cycle was not geographically uniform, reporting that roughly two-thirds of the area burned repeatedly in sagebrush occurred in the Snake River Plain in southern Idaho.
during a recent 30-year period. Crist et al. (2021) reported that most areas with recurrent fire in sagebrush ecosytems burned twice (71%) resulting in an average fire return interval of 15 years for those areas. They found that the remaining 29% of areas with recurrent fire burned three or more times for an average fire return interval of 7.5 years or less. Considering 82% of seeding treatments in our analysis were postfire restoration treatments, it is no surprise that this fire return interval estimate (7.5–15 years) is similar to the time-since-seeding values that we report here (i.e., average time between seeding and burning was 9.89 years for seedings in the Snake River Plain). Variation in the timing of recurrent fire and burn frequency may be influenced by a number of factors, including whether an area was drill seeded with grasses that effectively outcompete cheatgrass (e.g., various wheatgrasses, *Agropyron* spp.) and whether a seeded area is more mesic or arid (Bowman-Prideaux, Newingham, & Strand, 2021).

Finally, our findings also can allow for analytical tests of effectiveness after the fuel treatment network has been installed. Such information is needed to evaluate and improve our understanding of how fuel breaks and fuel management decisions influence wildfire frequency, rate of spread, and size, as well as their efficacy for the protection of life, property, and priority natural resources. The scientific basis justifying the installation of massive fuel break networks across these vulnerable, yet fragile landscapes is important, but we may no longer have the luxury of time, as the widespread loss of these ecosystems and their social and ecological services are increasingly apparent. Geographic prioritization of management interventions, as suggested by our findings, could help buy additional time in places most vulnerable to reburning. Finally, we recognize that fuel breaks are just one component of an overall fire management strategy and we acknowledge that these strategies are improving.

5 | CONCLUSIONS

The invasive grass-fire cycle in the western United States is one of the most difficult and complex socio-ecological problems facing natural resource managers (Brooks et al., 2004; D’Antonio & Vitousek, 1992). The once vast sagebrush shrublands are being consumed by wildfires far faster than they can recover (Knutson et al., 2014; Shriver et al., 2018) and areas that burn repeatedly may convert permanently to grasslands dominated by non-native grasses and forbs (Chambers, Maestas, et al., 2017; Pilliod, Welty, & Arkle, 2017). The loss of sagebrush, a foundational species of the American west, has ecological and socioeconomic consequences (Brunson & Tanaka, 2011; Coates et al., 2016). Efforts to restore sagebrush shrublands to prefire characteristics is underway but is difficult and can take decades (Brabec et al., 2015; Grant-Hoffman & Plank, 2021; Pyke et al., 2020). Thus, protecting those areas with prior restoration investment so they have time to recover may be as important as protecting remaining intact sagebrush with strategically placed fire breaks, targeted invasive species and fine fuels management (i.e., mowing, grazing, herbicide), and suppression tactics (Ricca & Coates, 2020).

Although we offer no recommendations here, it may be prudent to also consider other management interventions or other types of fuel treatments, and perhaps to even rethink how the sagebrush ecosystems are managed (Davies, Leger, Boyd, & Hallett, 2021). The confounding effects of invasive species, natural disturbances, and climate change, such as we are experiencing with the cheatgrass-fire cycle in the western United States, are wicked problems that will require creative, timely, and yet adaptive solutions involving strong partnerships and tough decisions that sometimes must be made prior to having all of the information that we would like. An adaptive management approach may provide BLM the opportunity to determine whether the fuel breaks and treatments proposed in the PEISs are at the right scale, are placed effectively, and are the right type of management intervention to offer protection to remaining restoration seedings and other priority resources. In the coming years, it will be interesting to track the effectiveness and outcomes of this grand experiment of wildfire and natural resource management—information that could prove useful for other fire-prone shrubland and grassland regions of the world.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

AUTHOR CONTRIBUTIONS

David Pilliod, Michelle Jeffries, Justin Welty, and Robert Arkle contributed to the conceptualization of the ideas. Michelle Jeffries conducted the data analysis and prepared the figures. All authors wrote and edited the manuscript.
DATA AVAILABILITY STATEMENT

The data used in the analyses are openly available to the public and were accessed in January 2021. Land treatment records were acquired from https://doi.org/10.5066/P980BOLS. Wildfire data were acquired from https://doi.org/10.5066/P9Z2VVRT and https://data-nif.opendata.arcgis.com/datasets/current-wildfire-perimeters-1. The BLM boundaries were taken directly from the Programmatic Environmental Impact Statement Record of Decisions available on https://eplanning.blm.gov. Full citations can be found in the references. The interactive graphical supplement is available at the following URL: https://doi.org/10.5066/P931LUJ1.

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