Stranded land constrains public land management and contributes to larger fires

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Abstract
Wildfire activity in the western United States has been increasing since the 1970s, with many fires occurring on land managed by government agencies. Over six million acres of public lands are surrounded by private land and lack road access, making them legally inaccessible to federal and state agencies and potentially constraining management and suppression of wildfires. In this paper, we assemble data on all fires that started on public lands in the western US over the period 1992–2015 and estimate the effect of legal accessibility on fire size. We find that ignitions are 14%–23% more likely to become large (greater than one acre) if they occur on inaccessible land. We provide evidence that this effect may be driven in part by agencies’ inability to conduct fuels management and in part by slower suppression responses on legally inaccessible land. Our results suggest that wildfire prevention and suppression could be bolstered by improved access to public lands and underscore the need for ongoing research on the relationship between land ownership and wildfire.

1. Introduction
Wildfire activity in the western US—including the number of large fires and total area burned—has increased in recent decades (Dennison et al 2014, Westerling 2016). While fire is a natural and ecologically beneficial disturbance on many landscapes, it can also cause substantial property damage (Wang et al 2020) and is a significant source of air pollution, including particulate matter (Burke et al 2021) and greenhouse gases (Van Der Werf et al 2017). As well, wildfires present a financial challenge for federal agencies, who spent $3.14 billion fighting wildfire in 2018—more than a five-fold increase since 1985 (National Interagency Fire Center 2020)—and whose budgets are increasingly consumed by firefighting expenses (Steelman 2016).

Increases in wildfire activity in the western US are primarily attributed to the combined effects of climate change (Jolly et al 2015, Abatzoglou and Williams 2016) and decades of fire exclusion, beginning in the late nineteenth century (Marlon et al 2012). Fire is the primary natural disturbance influencing ecosystems throughout the western U.S. (Noss et al 2006). While historical fire regimes vary greatly across western ecosystems (Schmidt 2002), humans have altered fire regimes by modifying fuels through fire exclusion and land-use change and increasing ignitions, 80% of which are human-caused in the region (Aires et al 2016, Balch et al 2017). Due to the history of fire exclusion, vegetation has accumulated in many western forests and now fuels larger and more hazardous wildfires (Hessburg et al 2005, Naficy et al 2010).

Because of the vast federal landholdings throughout the western US, the federal government has played an important role in managing the lands on which fires frequently take place, and in responding to fires when they occur. The federal government owns and manages 46% of the land in the 11 western states (Congressional Research Service 2020). For decades, the US Forest Service (USFS) employed a zero-tolerance policy toward fire on its lands. Due to such policies, fuel treatments and forest restoration
projects are now needed on up to 80 million acres of the USFS’s 200 million total acres of landholdings, and current efforts are not keeping pace with historic disturbance rates (North et al 2012, Buford et al 2015, Vaillant and Reinhardt 2017). Though there is now greater recognition that rapid containment of wildfires is not an appropriate goal in all cases and some wildfires may provide opportunities for cost-effective fuels management (Calkin et al 2015, Boisramé et al 2017), quick containment of fires that threaten lives and property is an important strategy for minimizing damages and management costs.

Unfortunately, barriers to access may impede both fuels management and fire suppression, which are needed to mitigate wildfire damage. Studies have found physical accessibility aids wildfire suppression efforts. Fire perimeters are more likely to coincide with roads (Narayanaraj and Wimberly 2011, Dunn et al 2020, Thompson et al 2021) in part because production of fire control lines is more efficient near roads (Katuwal et al 2016). Lack of access may also inhibit fuels management, especially for mechanical treatments that require yarding of fuels (Agee and Skinner 2005; Thompson et al 2017).

Access problems are often connected to the spatial pattern of land ownership, which previous studies find can have important effects on the occurrence and characteristics of wildfire. Empirical analyses show that land ownership affects fire probability (Staats et al 2017) and severity (Zald and Dunn 2018) and that larger fires are associated with public wilderness and roadless areas (Narayanaraj and Wimberly 2012, Johnston et al 2021). Theoretical studies find that incentives for fuels management are reduced on landscapes with fragmented ownership (Busby et al 2012) and that policy interventions may be needed to optimally manage fire risk (Lauer et al 2020). Finally, several studies have considered organizations for wildfire management and how institutions can be designed to manage wildfire on landscapes with fragmented ownership (Stasiewicz and Paveglio 2018, Charnley et al 2020).

In this paper, we study an unexplored dimension of the relationship between ownership, access, and fire on public land: how stranded lands affect fire outcomes. Most state and federal land in the West (92%) is designated as ‘public access,’ meaning that it is open to the public for recreation and other activities. Nevertheless, some of these lands are inaccessible to land managers and most of the public. In some cases, public lands are completely surrounded by private land and hence cannot be accessed by public roads or trails. ‘Checkerboarded’ areas with patchworks of private and public land also impair access because ‘crossing corners’ from one public parcel to another is considered trespassing across the adjacent private lands (General Accounting Office 1992). Therefore, without landowner permission, these ‘stranded’ lands that do not touch public roads are legally inaccessible to agency managers (Chavez 1987). Stranded lands are a legacy of 19th century land disposal policies (see supplementary materials (available online at stacks.iop.org/ERL/16/114014/mmedia)), and they provide a unique opportunity to study how legal access affects wildfires, an important outcome related to federal agencies’ ability to manage and respond to hazards on its lands.

In addition to investigating the effects of public stranded lands, we provide indirect, supporting evidence on the role of legal accessibility and land and fire management in contributing to fire outcomes. While data limitations prevent us from providing conclusive evidence on the relationship between stranded lands, fuel treatments, and fires, we are able to investigate linkages between both stranded lands and rates of fuel treatment and rates of fuel treatment and fire size on the subset of federal lands managed by the USFS. We explore the following questions:

(a) What is the extent and distribution of wildfire on stranded public lands?
(b) How does legal accessibility to public lands in the western U.S., measured by strandedness, affect wildfire size?
(c) How does legal accessibility affect land management activities such as fuel treatments?
(d) To what extent do fuels management and/or wildfire suppression activities contribute to the relationship between accessibility and fire size?

Our results on these research questions add to a growing body of literature on the role of land management and fuels treatments (reviewed in Kalies and Kent 2018).

2. Data and methods

2.1. Data

Our estimates of the location and extent of stranded public land come from Leonard and Plantinga (2020). They combine GIS data on public land ownership and easements from the Protected Areas Database of the United States (U.S. Geological Survey 2019) with data on public roads from the US Census TIGER/Line (US Census Bureau 2019) shapefiles to quantify the extent of stranded public land in each county in the 11 western States. The estimates consider land that is designated as public access and managed by a state government, the bureau of land management, the USFS, the Fish and Wildlife Service, the national parks service, or the bureau of reclamation. Leonard and Plantinga (2020) estimate that 6019 305 acres of public access
land in the West are legally inaccessible, representing about 1.5% of the total. Figure 1 depicts the spatial distribution of stranded land across the entire western US.

Fire ignition locations come from the USFS fire occurrence database (FOD), which reports dates, final fire sizes, ignition cause, geographic coordinates accurate to within 1 square mile, and several other characteristics for 1.9 million US fires between 1992 and 2015 (Short 2017). The FOD aggregates standardized incident reports from various federal, state, local, and tribal firefighting agencies. We focus on fire ignitions occurring on public lands within the western US, yielding a fire-level data set containing over 258,000 ignitions. We overlay the ignitions data with the stranded lands data to determine whether each ignition took place on accessible or inaccessible public land. Figure 2 depicts an example map of ignition locations along with accessible and inaccessible public land in Meagher County, Montana.

Data on fuels management activities on public lands come from the USFS Forest Activity Tracking System (FACTS) database. FACTS reports projects on USFS lands that are intended to reduce fuels or manipulate vegetation for the purposes of maintaining resilient landscapes (US Forest Service 2020). The FACTS data include GIS polygons that record the location, date, and type of each project, beginning in 2005. We identify fire ignitions that occur within the polygons associated with FACTS projects implemented prior to the date of the fire. From these, we identify the subset of ignitions associated with FACTS treatments intended specifically to reduce wildfire hazard (activity codes 1000–2000). We also overlay the FACTS polygons with public land polygons to identify projects that occurred on stranded and non-stranded parcels of public land.

We construct a suite of other covariates that have been shown to affect the intensity, severity, spread, and cost of suppressing wildfires. Mean elevation and ruggedness (measured as the standard deviation of elevation within a township) come from the National Elevation Dataset (U.S. Geological Survey 2019), which provides estimated elevation at a 30 × 30 m resolution. Data on land use and development come from the National Wall-to-Wall Land Use Trends Database (Falcone 2015). Finally, we measure fuel type at each fire ignition location using the Anderson 13 Fire Behavior Fuel Models data set from the US Department of Agriculture and US Department of Interior Landfire program (Earth Resources Observation and Science Center (EROS), U.S. Geological Survey 2019). More detail describing the construction of these variables is available in section A.2.

Table A.1 reports the summary statistics for the fire-level data set. Table A.2 reports the mean of each covariate separately for stranded (column 1) and non-stranded fires (column 2). Summary statistics for the public land unit (PLU)-level data set are available in tables A.3 (all land) and A.4 (USFS lands only). Table A.5 reports the share of each PLU that is associated with each major fuel category from the Anderson 13 Fire Model for stranded vs. non-stranded land.

2.2. Empirical approach

2.2.1. Stranded land and fire size (questions (a) and (b))

We estimate a linear regression model to investigate whether legal accessibility affects fire size ($\text{Size}$),
where in the primary analysis, the unit of observation is a fire, indexed by $i$. The model is written:

$$I(\text{Size}_i > C) = \alpha \text{Stranded}_i + X_i'\beta + \gamma_c + \delta_m + \omega_t + \lambda_k + \eta_a + \epsilon_i, \quad (1)$$

where $C$ is a chosen size threshold, $\text{Stranded}_i$ is an indicator variable for whether fire $i$ started on legally-inaccessible public land, $X_i$ is a vector of covariates, $\gamma_c$ is a county fixed effect (a dummy variable equal to one if fire $i$ starts in county $c$), $\delta_m$ is a month-of-year fixed effect, $\omega_t$ is a year fixed effect, $\lambda_k$ is a fixed effect for a fire’s cause (see supplementary materials), $\eta_a$ is a fixed effect for the public agency with management authority at the ignition point, and $\epsilon_i$ is a random error term. The fixed effects amount to separate intercepts for each year, month-of-year, cause, or management agency reported in the data. The fixed effects control for any unobserved factors that affect fire size within a given category (Wooldridge 2002), hence our estimates are derived from comparisons of fires within each category of fixed effects, ruling out omitted variable bias associated with those factors.

The vector $X_i$ includes controls for various observable factors known to affect fire behavior or fire management. These variables include topography (Finney 2004, Dillon et al 2011), development (Baylis and Boomhower 2019, Plantinga et al 2020), fuel type (Gebert et al 2007), and physical (vs. legal) road access (Narayanaraj and Wimberly 2011) associated with each fire ignition in our data. Covariates are measured at the Public Land Survey System township level and merged with individual fires based on the township in which the ignition occurred (PLSS townships form a regular grid of 6 × 6-mile squares across the western United States).

Equation (1) assumes a linear relationship between the probability of escape and the covariates of interest. We estimate equation (1) as a linear probability model (rather than a non-linear binary response model such as logit) because it allows us to include large numbers of fixed effects and because our main interest is in coefficient estimates at the mean of the data and not out-of-sample prediction. In addition, the assumption of linearity allows us to address heteroskedasticity and spatial correlation in a flexible way by clustering standard errors by county. As we show in the supplementary materials, the assumption of linearity appears valid in our setting based on the share of predicted values that lie between zero and one. We report the estimated coefficients in the main text and figures. We also estimate a series of alternative versions of equation (1) using different combinations of fixed effects and controls and alternative definitions of the dependent variable and control variables to test whether our findings are robust to changes in the model specification. These results can be found in the supplementary materials.

Our primary outcome variable is a binary indicator for whether final fire size exceeded a threshold fire size, at which point we say the fire has ‘escaped.’ In wildfire management, there is no consistent fire size at which a fire is said to have ‘escaped’ initial attack. Initial attack refers to efforts by the first firefighting
Figure 3. Estimated densities of fire size. This figure depicts smoothed kernel density estimates of fire size for all ignitions on stranded (red) and non-stranded (grey) land. The dashed vertical line distinguishes fires that exceed 1 acre, which is the threshold for our primary outcome of interest. All fires exceeding 10 acres are grouped into a single category.

resources on the scene to rapidly contain a fire within the first 1–8 h (Lee et al 2013). Based on the distributions of fire size observed in figure 3, we choose a threshold fire size of 1 acre for our main specifications, though we demonstrate the robustness of our results to alternative size thresholds in the supplementary materials.

Next, we compare the total number of ignitions per acre on stranded vs. non-stranded PLUs to ensure that differences in escape probabilities are not driven by differences in the number of fires on each type of land. It is possible that very small fires are less likely to be reported on stranded land if they do not require a suppression response. This could introduce denominator bias into our estimates—i.e. the share of reported large fires may be artificially large on stranded land. If denominator bias were driving our results, we would expect to see fewer fires per acre on stranded land than on non-stranded lands. We estimate:

\[ Ignitions_k = \sigma_{Stranded} + X_k'\beta + \gamma_c + \epsilon_k, \quad (2) \]

where \( \sigma \) indexes a given PLU, and the variables in \( X_k \) include the log of the size of the PLU area and the share of developed land within a nine-mile radius of the centroid of the PLU. Fixed effects for the county associated with PLU \( i \) are denoted \( \gamma_c \). We estimate equation (2) using a linear regression model and weight observations based on their size in acres. We test robustness of our estimates of equation (2) to alternative specifications in the supplementary materials.

2.2.2. Fuels treatments, stranded land, and fire size (questions (c) and (d))

To explore mechanisms, we test whether stranded lands are more or less likely to receive fuels treatments by estimating:

\[ y_k = \alpha_{Stranded} + X_k'\beta + \gamma_c + \epsilon_k, \quad (3) \]

where \( y_k \) is alternately an indicator for whether a land unit \( k \) ever had any management activity applied to it, or an indicator for whether a fuels treatment had ever been applied to it. The vector \( X_k \) is defined as in equation (2), and we include county-level fixed effects as in equation (2). We estimate equation (3) for USFS lands only because we lack data on treatment activities for non-USFS lands. We test alternative specifications of equation (3) in the supplementary materials.

Finally, to explore the effects of fuels treatments themselves on fire size, we estimate a version of equation (1) but replace \( Stranded_k \) with a dummy variable for whether a fuels treatment was previously applied at the ignition point. Because there are so few fuels treatments applied on stranded lands, we estimate this model only with fires that start on accessible public lands. The results are reported in table A.13 with specifications that mimic table A.6. The sample for this table is limited to USFS lands because we lack information about whether or not fuels treatments have occurred on non-USFS land. Though constrained by data limitations, these models can still provide suggestive evidence on the relationship between fuels treatments and fire size that is helpful for interpreting the main effects of interest.

3. Results

3.1. The extent and distribution of stranded fires

There are 1721 fires on stranded land and 256 056 on non-stranded land across the study region. Stranded fires tend to be at lower, less rugged locations, closer to development, but farther from roads. Stranded fires are less likely to occur in wilderness areas. Stranded fires are slightly more likely to occur in grasslands and less likely to occur in timber lands,
but these differences attenuate and become insignificant with fixed effects (column 5 of table A.2). There are no statistically significant differences in the share of land in each fuel class across stranded and non-stranded land. In total, fires that began on stranded land burned 888,641 acres, while fires that began on non-stranded land burned 50,168,314 acres.

To provide initial evidence on the distributions of fire size and the role of stranded lands, and to help in selecting an appropriate size threshold \( C \) (from equation (1)), figure 3 plots smoothed kernel density estimates of fire size for all fires beginning on stranded (red) and non-stranded (gray) western public lands between 1992 and 2015. Fires larger than 10 acres are grouped into a single category. Most fires remain smaller than 1 acre, regardless of whether they begin on stranded or non-stranded lands. For fires ranging from roughly 1 to 10 acres, the distribution of fire size is similar across both types of public land. However, the density of fires smaller than one acre is notably lower for stranded land, just as the density of fires that exceed 10 acres is notably higher.

Although stranded fires are less common than fires on accessible public land, they account for a disproportionate amount of area burned in certain locations. Fires that began on stranded land accounted for roughly 10% of total area burned in Montana, Nevada, and Wyoming, despite the fact that only 3%–6% of ignitions occurred on stranded land in those states. Elsewhere, this phenomenon is less pronounced: roughly 1% of public land ignitions occur on stranded land in Colorado, Idaho, New Mexico, Oregon, and Utah, accounting for 0.27%–1.5% of area burned (table 1). These differences are due to the large variation in average fire size for stranded vs. non-stranded fires in each state. As table 1 indicates, stranded fires are 2–3 times as large as non-stranded fires on average, in Montana, Nevada, and Wyoming, where they account for a disproportionate amount of area burned. As figure 1 indicates, those states also have larger shares of stranded land.

### 3.2. Stranded land increases fire size

Figure 4 shows that the coefficient on the Stranded dummy variable associated with estimating equation (1) is significantly different from zero at the 1% confidence level, indicating that fires are 4.12 percentage points more likely to escape if they begin on stranded public land than if they begin on accessible public land. The baseline probability of escape in the sample is 19.2%, which implies that stranded land increases escape probability by 100 × 0.0412 = 21.5%. Fires that begin in wilderness areas are also more likely to escape containment by 4.87 percentage points (a 25% increase). Results that demonstrate the robustness of our core finding across alternative specifications and fire size thresholds are available in the supplementary materials (tables A.7–A.10).

Stranded public lands experienced, on average, nearly one more fire per 500 acres than did non-stranded lands over the time span of our data (table A.11). However, after the inclusion of county fixed effects and controls for acres and proximity to development, there is no difference between ignitions per acre on stranded and non-stranded lands. Hence, fires are not more likely to occur on stranded lands, after controlling for land characteristics. Finally, results suggest that the marginal effect of strandedness on the probability of escape is greatest for fires that begin in grass or shrublands (where fire tends to spread more rapidly), and is not significantly different from zero for fires that begin on slash or timber lands (figure A.11).

### 3.3. Stranded USFS lands reduce fuels treatments

Stranded lands are 5.14 percentage points less likely to receive a management project than non-stranded land (panel (a) of figure 5). The baseline probability

### Table 1. Extent of stranded fires. This table reports the percentage of ignitions that begin on stranded land, the percentage of area burned by fires that begin on stranded land, average fire size for stranded fires, average fire size for non-stranded fires, and the ratio of average fire sizes for stranded vs. non-stranded fires for each county in our sample.

| State      | Stranded % of ignitions | Stranded % of area burned | Avg. stranded fire size | Avg. non-stranded fire size | Avg. stranded fire/Avg. non-stranded fire |
|------------|-------------------------|---------------------------|-------------------------|-----------------------------|-----------------------------------------|
| Arizona    | 0.669                   | 0.27                      | 44.823                  | 111.487                     | 0.404                                   |
| California | 2.052                   | 1.882                     | 136.272                 | 148.892                     | 0.917                                   |
| Colorado   | 1.183                   | 1.307                     | 52.499                  | 47.478                      | 1.104                                   |
| Idaho      | 1.118                   | 1.234                     | 493.657                 | 447.28                      | 1.102                                   |
| Montana    | 3.121                   | 8.394                     | 529.813                 | 186.286                     | 2.689                                   |
| New Mexico | 1.506                   | 0.939                     | 131.128                 | 211.361                     | 0.624                                   |
| Nevada     | 3.091                   | 10.305                    | 1668.49                 | 463.149                     | 3.334                                   |
| Oregon     | 1.249                   | 1.731                     | 242.767                 | 174.352                     | 1.386                                   |
| Utah       | 0.779                   | 1.586                     | 314.25                  | 153.168                     | 2.055                                   |
| Washington | 2.023                   | 3.281                     | 295.917                 | 180.126                     | 1.622                                   |
| Wyoming    | 6.444                   | 11.136                    | 330.609                 | 181.72                      | 1.728                                   |
| Overall    | 1.699                   | 2.655                     | 299.562                 | 194.603                     | 1.313                                   |
Figure 4. The effect of stranded land on fire size. This figure depicts the results of estimating equation (1) with a linear probability model. The unit of observation is a fire ignition and the dependent variable is an indicator that is equal to one if a fire grows to exceed one acre. All non-binary variables were standardized for ease of interpretation. The model includes fixed effects for the year of the fire and month-of-year to account for changing fire activity over time and throughout the year. We also include fixed effects for county, agency (BLM, USFS, etc) and cause (lightning, machinery, etc). Full results and robustness to additional specifications are provided in table A.6.

Figure 5. The effect of stranded land on fuels treatments. This figure depicts coefficients from estimating equation (3). The unit of observation is a public land unit (PLU): a contiguous tract of public land. The dependent variable in panel (a) is an indicator that is equal to one if a PLU spatially overlaps any Forest Service Activity Tracking System (FACTS) polygons, indicating that some sort of vegetation management took place. In panel (b), the dependent variable is an indicator that is equal to one if a PLU received a fuels treatment specifically aimed at reducing wildfire hazard (activity codes 1000–2000) since 2005, the first year in which the FACTS data are available. Italics denote an indicator variable. All models include county fixed effects. The estimating sample includes only USFS lands. Non-binary control variables were standardized for ease of interpretation. Full results are available in table A.12. These results rely on the assumption of the FACTS database being accurate.

3.4. Fuels treatments reduce fire size on USFS lands
On accessible USFS land, fuels treatments reduce escape probability by 12.6 percentage points (figure 6, table A.13). Relative to the baseline escape probability of 17.2%, this is a 100 × 0.126 = 73.3% decrease in escape probability. The coefficient estimates for the other covariates are similar to those in figure 4. Fires that begin in grass or shrub-dominated landscapes were significantly more likely to have received a prior treatment at the 1% confidence level (table A.14). The estimated effect is 3.17–3.38 percentage points, representing a 28%–30% increase in the probability of a prior treatment.
4. Discussion

This paper uses data spanning over 250,000 fires across more than two decades to provide new evidence that a previously under-studied dimension of management—stranded land—has important impacts on wildfire. We combine administrative data on fire ignitions, land ownership, and road access with satellite data on land cover and terrain to flexibly control for various confounding factors that contribute to fire size across the entire western US. Our key finding is that fires are more likely to escape initial attack (the attempt to rapidly contain a fire within the first 1–8 h) on legally inaccessible—‘stranded’—parcels of public lands.

The majority of fire suppression costs and damages result from large fires (Calkin et al. 2005, CalFire 2020), but relatively few fires grow to exceed one or even ten acres. Hence, studying the extent to which land ownership and management affect the probability that fires escape containment is a crucial dimension for the study of wildfire. Although we focus on one acre as the threshold for ‘escape,’ we find similar effects of strandedness on fire size. First, land management agencies may engage in fewer fuels treatments on stranded land. Fuel treatments—including mechanical thinning and prescribed fire—are a primary management tool used by the USFS and other public land management agencies to reduce fire hazard (Agee and Skinner 2005, Stephens et al. 2012). Between 2002 and 2012, federal land management agencies spent approximately $500 million per year on fuel treatments, and treated 1.1 million hectares annually between 2002 and 2006 (Gorte 2011, 2013). It may be difficult to implement these management activities on stranded parcels, however, because accessing these parcels requires crossing private lands (Chavez 1987, General Accounting Office 1992).

Although data limitations prevent a definitive statistical test of the relationship between...
strandedness, fuels treatments, and fire size, we find that stranded USFS parcels are less likely to receive fuels treatments than non-stranded USFS parcels and that fuels treatments on non-stranded USFS parcels are effective at reducing fire sizes. Together, these results suggest that differences in management—such as rates of fuel treatment—are a probable factor contributing to the observed relationship between strandedness and fire size. This finding adds to the growing evidence that fuels treatments can be effective in controlling fire size (Syphard et al 2011, Penman et al 2013, Oliveira et al 2016). While these results are specific to USFS lands (where fuels treatment data are available), they provide suggestive evidence that is consistent with the hypothesis that strandedness impairs land management. Moreover, the fact that the effects persist even after flexibly controlling for PLU size and distance to roads and developed areas suggests that stranded parcels are not treated at lower rates only because they are isolated, but also because they are legally inaccessible.

In addition to fuels management, the effects of fire size on strandedness may be related to differences in suppression responses. Suppression may be more difficult on stranded parcels both because they are not legally accessible and because they are less physically accessible by road. Roads have been found in previous studies to influence fire cessation (Narayanaraj and Wimberly 2011), total burned area (Narayanaraj and Wimberly 2012), and burn severity (Narayanaraj and Wimberly 2013). However, although suppression response may be delayed on stranded public lands, we think it is unlikely that differences in suppression response associated with physical accessibility are driving our results since controlling semi-parametrically for proximity to road does not substantially diminish the estimated effect of strandedness on fire size (table A.6). Similarly, the impact of stranded land on the probability of escape remains after controlling for the ruggedness, elevation, and development density of the area where an ignition occurs.

Suppression may play a role through differences in legal accessibility that create additional barriers and slow the initial attack. Responding to fires on stranded land may involve logistical hurdles—determining jurisdiction, contacting landowners, and even confronting unexpectedly locked gates (General Accounting Office 1992)—that slow response time, even when landowners are cooperative. Even minor delays in response time could conceivably affect the likelihood a fire grows larger than one acre, especially for fires in grass and shrub/chaparral, fuel types through which fire spreads especially quickly (Anderson 1982) and on which we observe the strongest relationship between strandedness and fire size. Hence, it is possible that legal barriers to access on stranded land have practical implications for fire management that slow or even prevent responses to ignitions. It is also possible that stranded, fragmented lands are less of a priority for agency managers. The results here suggest that improving access to stranded land could help reduce the spread of fire.

Altogether, our findings suggest that legal inaccessibility imposes constraints on wildfire management that affect wildfire outcomes on stranded lands. While immediate suppression is not always an optimal response—in some cases, managed wildfires may provide opportunities for cost-effective fuels management (North et al 2012)—the rapid containment of fires that pose threats to lives and property is nevertheless an important goal of fire management (Liang et al 2008, Gude et al 2013). We find that strandedness increases fire size even after controlling for proximity to development and other factors that may affect the desirability of rapid containment. Therefore, strandedness may constrain and prevent effective responses to fires for which quick containment would be desirable. Hence, broader efforts currently underway to improve access to public land (e.g. the Great American Outdoors Act) should also consider the implications for wildfire prevention and suppression.

Furthermore, our findings have implications for policies related to federal land consolidation, and to federal land management more generally. Though stranded lands make up a small percentage of public lands, the influence of strandedness on management has real consequences for wildfire, an outcome of primary concern for public land managers. Federal land management may therefore benefit from land swaps to consolidate fragmented private and public land holdings. More broadly, our results add to the recent body of literature (reviewed in Kalies and Kent 2016) providing evidence on the important role of management in influencing outcomes in wildfire events. Significantly more empirical evidence on this topic is needed, given the threat wildfire poses to western communities and the backlog of federal acres in need of treatment (Vaillant and Reinhardt 2017). This paper suggests additional research priorities by highlighting difficulties that isolated and inaccessible stranded lands may present for management, while providing new insights regarding the effects of management on fire outcomes.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

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