Aplet *et al. Fire Ecology* (2026) 22:8
https://doi.org/10.1186/s42408-026-00450-2

Fire Ecology

RESEARCH

Open Access

Three-decade record of contiguous-U.S. national forest wildfires indicates increased density of ignitions near roads

Gregory H. Aplet[1*], Phil Hartger[1] and Matthew S. Dietz[2]

Abstract

Background Roads play an important role in managing fire on the national forests. But roads also are known to increase ignitions and damage ecosystems. Roads may limit the size of wildfires, which may be viewed as desirable where fires endanger human life and property or undesirable if roadlessness allows more land to experience the ecological benefits of fire. In this paper, we examine a large, nationwide dataset to determine whether roads on the national forests are associated with higher ignition density, and we examine patterns of fire size to see whether wilderness and roadless areas are associated with larger fires.

Results From 1992 to 2024, in all 8 contiguous-US Forest Service regions combined, wildfire-ignition density was lowest in designated wilderness areas (1.75 fires/1000 hectares), followed closely by Inventoried Roadless Areas (1.97 fires/1000 ha). The highest wildfire-ignition density was in lands within 50 m of roads (7.99 fires/1000 ha), and the second highest wildfire-ignition density was in other national forest lands outside of the 50-m road buffers but not in wilderness or roadless areas (3.50 fires/1000 ha). For human-caused, natural, and undetermined fires, wildfire-ignition density decreased as distance to road increased, irrespective of designation categories such as "wilderness" or "roadless." In lands between 0 and 250 m from roads, 6 fires ignited per 1000 ha, whereas fewer than 2 fires ignited per 1000 ha at a distance class of over 2000 m from roads. Mean fire size varied by where the fire started: it was greatest in wilderness areas (239 ha), followed by Inventoried Roadless Areas (135 ha), roaded national forest lands outside of Inventoried Roadless Areas, wilderness, and the 50-m buffer (62 ha), and lands within the 50-m road buffer (49 ha). We found, however, that the largest 2% of fires had similar mean sizes and ignition densities regardless of where they started.

Conclusions Our results suggest that building roads into roadless areas is likely to result in more fires. These fires will, on average, be smaller than fires farther from roads, but there will be more of them, and some of them will grow to become large fires. Nevertheless, both roads and roadless areas can contribute to strategic, landscape-scale fire management.

Keywords Collaboration, Fire management, Suppression, Roadless areas, Potential Operational Delineations, Zones

*Correspondence:
Gregory H. Aplet
greg_aplet@tws.org
Full list of author information is available at the end of the article

Resumen

Antecedentes Las rutas juegan un rol importante en el manejo de incendios en bosques nacionales de los EEUU. Sin embargo, estas carreteras son conocidas por incrementar las igniciones y dañar los ecosistemas. Las carreteras pueden también limitar el tamaño de los incendios, lo que puede verse como deseables cuando la vida humana y propiedades están en peligro, o como indeseables cuando el no disponer de rutas permite tener más áreas para experimentar los beneficios ecológicos de los incendios. En este trabajo examinamos un conjunto de datos para determinar si a nivel de los bosques nacionales, estos datos están asociados con una más alta densidad de igniciones, y examinamos los patrones de tamaño de los incendios para determinar si las áreas silvestres y áreas sin rutas están asociadas con grandes incendios.

Resultados Desde 1992 y hasta 2024, en 8 regiones contiguas del Servicio Forestal de los EEUU, todas combinadas, la densidad de ignición de incendios fue menor en zonas designadas como áreas naturales (1,75 incendios cada 1000 ha), seguidas muy de cerca por áreas inventariados como "sin rutas" (1,97 igniciones cada 1000 ha). La densidad más alta de igniciones fue en tierras que lindaban dentro de los 50 m de una ruta (7,99 igniciones cada 1000 ha), y la segunda densidad más importante de igniciones fue en otro bosque nacional y por fuera de los 50 m de una ruta pero no en áreas naturales o sin rutas (3,50 igniciones cada 1000 ha). Para los casos de igniciones humanas, naturales, o indeterminadas, la densidad de las igniciones decreció a medida de que se incrementó la distancia a las rutas, independientemente de que estos lugares fueran clasificados como áreas naturales o sin rutas. En tierras que estaban entre 0 y 250 m de rutas, se iniciaron 6 fuegos cada 1000 ha, mientras que menos de 2 fuegos cada 1000 ha fueron iniciados en áreas más allá de los 2000 m de una ruta. El tamaño medio de los fuegos varió de acuerdo a dónde comenzó el mismo fuego: éstos fueron mayores en áreas naturales silvestres (239 ha) seguidas por áreas inventariadas como "sin rutas (135 ha)", dentro de bosques nacionales con rutas, áreas naturales, y de amortiguación fuera de los 50 m de rutas (62 ha), y en tierras dentro de áreas a 50 m a ambos lados de las rutas (49 ha). Encontramos, sin embargo, que los mayores incendios (2%) tuvieron similares tamaños medios independientemente del lugar de inicio del fuego.

Conclusiones Nuestros resultados sugieren que la construcción de rutas en áreas agrestes es probable que generen condiciones para que tengan mayor número de incendios. Esos fuegos, en promedio, son más pequeños que los que ocurren en áreas alejadas de las rutas, aunque sean más numerosos, y que algunos de ellos pueden transformarse en grandes incendios. Sin embargo, tanto las áreas con rutas, como las agrestes sin ellas, pueden contribuir al planeamiento estratégico sobre la gestión del fuego a escala de paisaje.

Background

Roads play an important role in managing fire on the national forests. First, and most obviously, roads provide access for suppression forces and have been credited with keeping some fires small where they exist (Stergiadou 2014; Laschi et al. 2019; Thompson et al. 2021). Related, but distinctly different, roads serve as tactical control locations, affording managers access to comparatively safe places from which to light backfires and conduct burn-out operations to rob oncoming fire of fuel (NWCG 1996; O'Connor et al. 2017; Yocom et al. 2019). Roads themselves serve as fuel breaks and can disrupt the spread of fire under less-than-extreme conditions (Dickson et al. 2006; Narayanaraj and Wimberly 2013; Thompson et al. 2021). They also provide convenient locations from which to construct fuel breaks and containment lines for prescribed fires that are lit when conditions are suitable, outside of fire season (Gucinski et al. 2001). For all these reasons, roads are considered critical to fire management, and increasing the road network has been recommended as a tactic to enhance the control of wildfire (Maffly 2019; Healy 2020).

However, roads also are known to increase ignition frequency. Several studies have found a strong positive relationship between wildfire ignitions and proximity to roads. Some have looked simply at road density and fire proximity (DellaSala and Frost 2001; Dickson et al. 2006; Arienti et al. 2009; Zumbrunnen et al. 2012); others have examined ignition density and distance to roads (Yang et al. 2006; Maingi and Henry 2007; Morrison 2007; Ricotta et al. 2018); and others have taken more sophisticated multivariate approaches to identify the factors that drive fire likelihood (Cardille et al. 2001; Brosofske et al. 2007; Narayanaraj and Wimberly 2012; Hawbaker et al. 2013; Camp and Krawchuk 2017). All of these studies have reached the same conclusion: proximity to roads increases fire occurrence. In contrast, Syphard et al. (2008) found that fire frequency increased with distance from roads in the Santa Monica Mountains, though they also concluded that "there are also even more remote areas that burn with much less frequency." It remains an open question whether the benefits of roads to fire management outweigh the costs of roads in increased ignitions. And, it must be noted, any additional costs of ignition come on top of other well-established impacts of roads on ecosystems, including fragmenting and degrading habitat (Reed et al. 1996), hindering the movement of wildlife (Nellemann et al. 2001), facilitating roadkill (Smith and Dodd 2003), increasing erosion and sedimentation (Johnson et al. 2002), disrupting hydrology (Jones et al. 2000), introducing harmful chemicals (Grant et al. 2003), and facilitating the spread of invasive plants (Healy 2020).

Roads, or lack thereof, may also influence the size of wildfires. In some cases, increased wildfire size could be viewed as undesirable, if the resulting fire endangers "highly valued resources and assets" (HVRA, i.e., "the things we care about"; Scott et al. 2013), and roads can help keep fires small. On the other hand, where increasing the influence of natural fires is desirable, disrupting the spread of fire could be viewed as a negative. Some researchers have found fires in wilderness and roadless areas to be larger than fires near roads and speculate that poor road access in these areas allows fires to "escape" suppression (Dickson et al. 2006; Syphard et al. 2007; Johnston et al. 2021). Alternatively, roadless areas can be places where incident managers choose to allow fires to burn, due to the low density of homes and other HVRA, while they focus suppression resources where they are most needed (Aplet 2019; Johnston et al. 2021). And of course, wilderness areas have long been the preferred location to allow natural fire to do its work reducing fuels, recycling nutrients, and creating habitat diversity (Miller and Aplet 2016; Parks 2025).

In this paper, we examine a large, nationwide dataset to determine whether roads on the national forests are indeed associated with higher ignition density, and we examine patterns of fire size to see whether wilderness and roadless areas are, in fact, associated with larger fires. While other researchers have examined the relationship of fire ignitions to distance from roads in smaller geographies, we expand this inquiry to the contiguous US. Here, we use a national dataset to evaluate the influence of both land-management class and distance from roads on ignition density in the national forests. We conclude by considering the implications of our findings for zoning the use of fire across the landscape, the utility of Potential Operational Delineations (Thompson et al. 2022), and the value of roads and roadless areas as strategic fire-management assets.

Methods

We identified wildfire ignitions on national forest lands in the contiguous US using the InFORM Fire Occurrence Data Records (2024) geospatial database, which includes fire occurrence records from 1992 to 2024. We developed the nationwide roads dataset by combining National Forest System roads data (National Forest System Roads 2024, Operational Maintenance Levels 2–5) with the TIGER/Line shapefiles (2024) data representing interstate, county, and local roads. We excluded Maintenance Level 1 roads because they are closed to motor vehicles.

To assess how road proximity and land-use designations influence wildfire ignitions on national forest lands in the contiguous US, we first applied a 50-m buffer (extending 50 m on each side of the road centerline, creating an edge-to-edge polygon that is 100 m wide) to the nationwide roads dataset and clipped the resulting buffer to national forest lands (National Forest System Lands 2024). This produced four zones in each of the eight national forest regions: (1) the 50-m road buffer, (2) Inventoried Roadless Areas (2024) more than 50 m from a road, (3) designated wilderness (National Wilderness Areas 2024) more than 50 m from a road, and (4) other national forest lands (i.e., areas outside wilderness, Inventoried Roadless Areas, and the 50-m buffer; see Table S1). We then intersected these zones with the locations of wildfire ignitions from the *InFORM* database. For each category, we evaluated the density of ignitions per unit area (wildfire ignitions/1000 hectares) across U.S. Forest Service (USFS) regions.

To determine whether observed differences were due to distance from road or simply to land-use designation, we assessed how wildfire-ignition density changes with increasing distance from roads on national forest lands generally. We created nine distance classes by applying a series of 250-m buffers—extending outward to 2000 m—to the nationwide roads dataset. We added a tenth distance class for wildfire ignitions beyond 2000 m. We then intersected the wildfire-ignition database with the distance classes and calculated the ignition density (wildfire ignitions/1000 hectares) for each distance class across all USFS lands. To better understand the causal patterns around ignitions, we also calculated wildfire-ignition density by fire-cause category: human-caused, natural, and undetermined, and we repeated the analysis for each Forest Service region outside of Alaska.

We also examined differences in wildfire size across land-use categories. Using the same classification applied above—50-m road buffer, Inventoried Roadless Areas, designated wilderness, and other national forest lands—we calculated mean and median fire size (in hectares) of fires that started in each category based on the reported size in the InFORM database. Because the largest wildfires cause the most damage and are of the greatest concern, we conducted a separate query of the largest 2% of wildfires that started on the national forests (approximating the proportion of wildfires that escape initial attack;

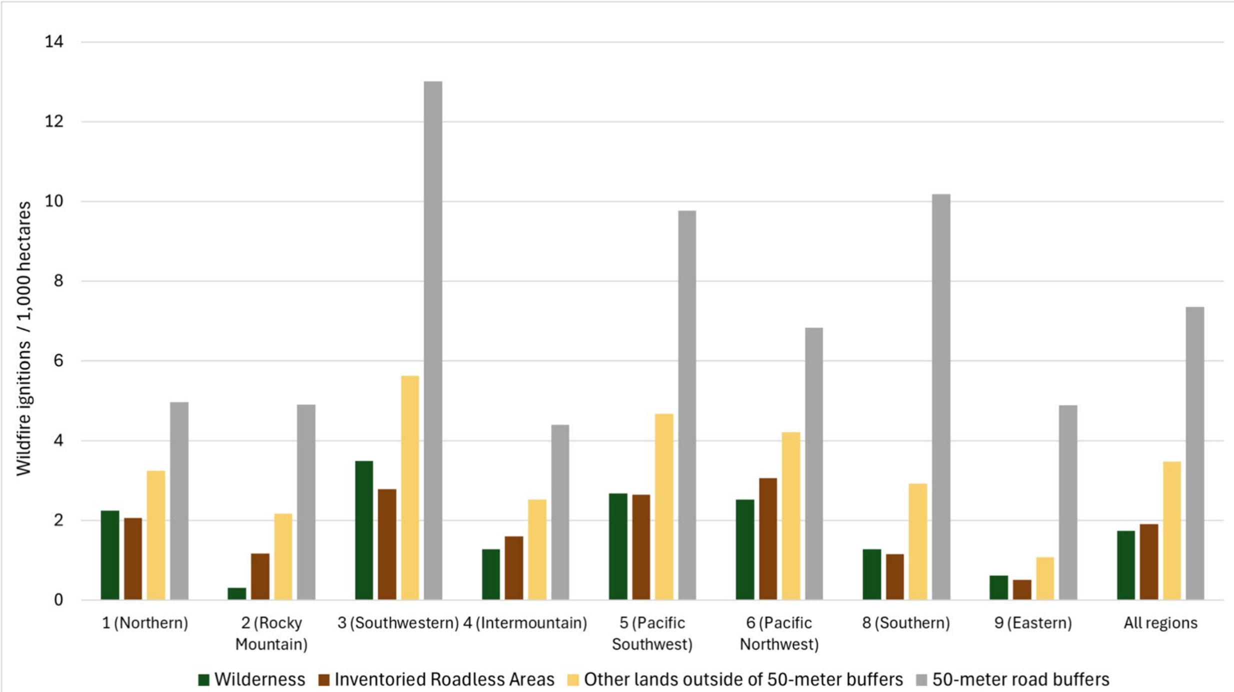

Fig. 1 Wildfire-ignition density across US Forest Service regions by wilderness, Inventoried Roadless Areas, other national forest lands outside of 50-m road buffers, and lands inside 50-m road buffers

Calkin et al. 2005) and examined the size distribution of fires that started within each land-use category. All analyses described above were performed on the entire population of recorded ignitions on the national forests between 1992 and 2024; therefore, inferential statistics were not needed to assess if observed differences were due to sampling error.

Results

Our 50-m road buffer identified 7.8 million hectares within 50 m of roads open to motor vehicle use across the national forests, or 11.3% of the system. Values ranged from 7.5% in the Intermountain Region to 17.2% in the Pacific Northwest (Table S1). Across the contiguous US, Inventoried Roadless Areas more than 50 m from a road made up 23.9% of the national forest landbase, and wilderness areas contributed another 18.2%, leaving just under half (46.6%) categorized as other national forest lands.

From 1992 to 2024, for the aggregated data across all 8 USFS regions, wildfire-ignition density was lowest in designated wilderness areas (1.75 fires/1000 hectares), followed closely by Inventoried Roadless Areas (1.97 fires/1000 ha). The highest wildfire-ignition density was in lands within 50 m of roads (7.99 fires/1000 ha), and the second highest wildfire-ignition density was in other national forest lands (3.50 fires/1000 ha; Fig. 1).

This pattern was similar across USFS regions. Highest wildfire-ignition density was always in lands within the 50-m buffer, and the second highest wildfire-ignition density was always in non-wilderness and non-roadless areas outside of the 50-m road buffer. The lowest density of wildfire ignitions differed by region, with five of the regions having lowest densities in roadless areas and three having lowest densities in wilderness areas (Fig. 1).

For all causes of wildfire ignitions combined—human-caused, natural, and undetermined—wildfire-ignition density decreased as distance to road increased, irrespective of designation categories such as "wilderness" or "roadless" (Fig. 2). In lands between 0 and 250 m from roads, 6 fires ignited per 1000 ha, whereas fewer than 2 fires ignited per 1000 ha at a distance class of over 2000 m from roads.

This pattern of decreasing ignition density at greater distances from roads appears to hold even with natural, lightning-caused fires and fires of undetermined origin (Fig. 2). It was most pronounced, however, with human-caused fires. At less than 250 m from roads, more than 3.5 human-caused fires ignited per 1000 ha, whereas fewer than 0.5 human-caused fires ignited per 1000 ha at distances over 2000 m from roads (Fig. 2). The numbers differed, but the pattern was the same for every Forest Service region (Fig. S1).

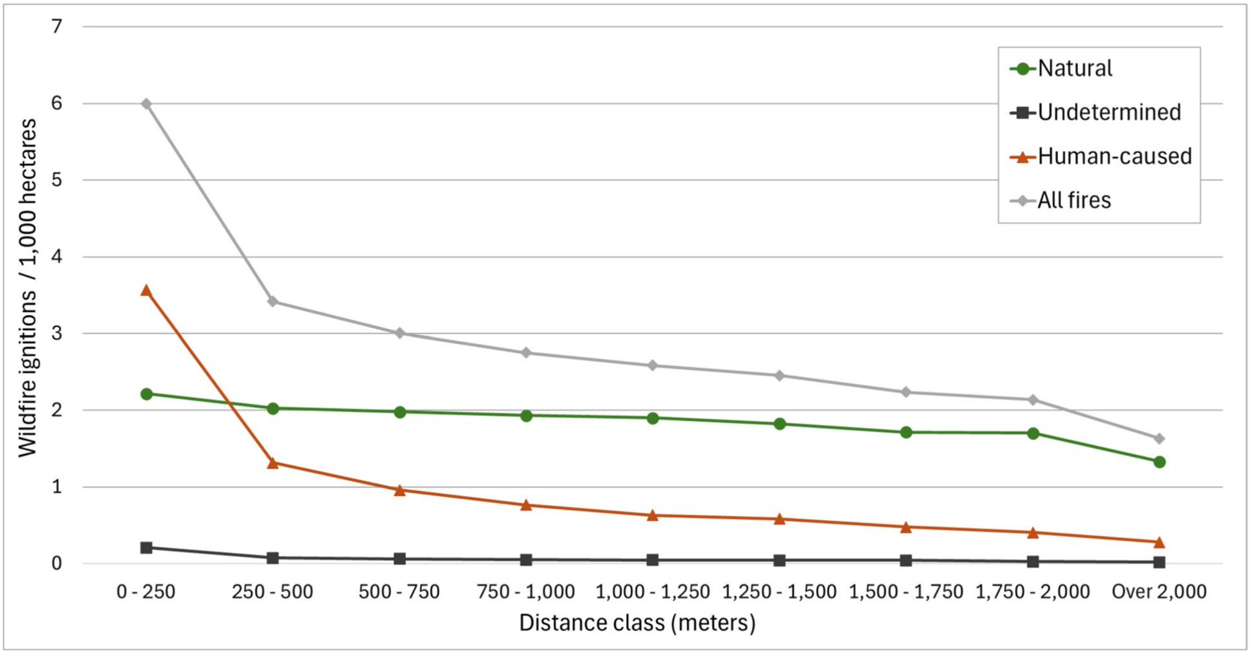

Fig. 2 Total wildfire-ignition density by cause across road-buffer-distance classes for all national forest lands in the contiguous US

Table 1 Summary statistics for wildfire size distribution across national forest land-use categories, using breaks typical of boxplots, for all fires that started on national forests and the largest 2% of fires that started on national forests. Values (in hectares) are displayed in tabular form, as the strong right-skew of the data confounded display as a boxplot figure. Table reflects only those fires for which a final area was recorded

	Number of fires	Minimum size	2nd percentile	25th percentile	Median	75th percentile	Mean	98th percentile	Maximum size
All fires									
Wilderness	22,335	0.004	0.04	0.04	0.04	0.4	239	1660	217,741
Inventoried Roadless Areas	34,186	0.004	0.04	0.04	0.04	0.2	135	551	202,321
50-m road buffers	62,376	0.004	0.04	0.04	0.04	0.2	49	59	389,838
Other national forest lands	112,995	0.004	0.04	0.04	0.04	0.4	62	113	167,497
Largest 2%									
Wilderness	1175	182	195	371	985	3046	4464	37,921	217,741
Inventoried Roadless Areas	1049	182	196	397	934	3115	4318	36,393	202,321
50-m road buffers	647	182	188	318	728	2698	4464	33,901	389,838
Other national forest lands	1781	182	188	320	728	2210	3811	40,685	167,497

Considering all ignitions, mean fire size was greatest in wilderness areas (239 ha), followed by Inventoried Roadless Areas (135 ha), other national forest lands (62 ha), and lands within the 50-m road buffer (49 ha) (Table 1). The median fire size, however, was similar for each category (0.04 ha) because the distribution of fire sizes was so strongly right-skewed, with most fires burning less than one-twentieth of a hectare and a small number of fires burning very large areas, regardless of the land-use category in which they ignited. In exploring the right tail of the distribution, we found the largest 2% of fires starting on national forests to include all fires larger than 182 ha (450 ac) and that the mean size and ignition density was about the same across categories (Table 1). Because of the strong skew to the data, the smallest "large" fire in every land-use class was 182 hectares, and the range of mean large-fire size among the 4 categories was between 3811 and 4464 ha and the median was between 728 and 985 ha. Ignition density of large fires was 9.35 fires/100,000 ha in wilderness, 6.35 fires/100,000 ha in Inventoried Roadless Areas, 8.26 fires/100,000 ha in the road buffer, and 5.52 fires/100,000 ha in other national forest lands.

Discussion

Our results show that ignition density is higher near roads than away from them. Across the National Forest System and in every region examined, the density of wildfire ignitions within 50 m of a road is higher than in wilderness, Inventoried Roadless Areas, or other national forest lands, often by quite a bit (Fig. 1). Additionally, ignition density in wilderness and roadless areas is lower than in roaded lands more than 50 m from a road. It is clear that, across the national forests, the existence of a road increases the density of ignitions.

This same relationship holds whether ignitions are human-caused or lightning-caused, though distance from roads clearly has a stronger influence on human-caused ignitions (Fig. 2), which drop off dramatically with distance, a pattern that holds across regions (Fig. S1). The ignition density of human-caused wildfires within 250 m of a road was more than three times greater than at any distance beyond 500 m during the study period and exceeded the ignition density of lightning fire near roads by almost twofold. Roads even appear to increase the ignition density of lightning-caused fire, though nowhere near as much as they influence human-caused fires. Both human- and lightning-caused ignitions decrease gradually with distance from roads beyond the immediate zone of influence for reasons that are not well understood (see below).

The influence of roads on fire size is harder to interpret, given the amount of variation in the data. The mean size of a fire starting within 50 m of a road is smaller (49 ha) than fires that start in wilderness (239 ha), Inventoried Roadless Areas (135 ha), or other areas (62 ha) beyond 50 m of a road, though the high variability makes it difficult to conclude a meaningful difference (Table 1). The median fire size in every land class is less than one-twentieth of a hectare, confirming that most fires go out, or are put out, when they are very small, regardless of where they occur on the landscape. Looking only at the largest 2% of fires, i.e., those fires that presumably escape initial attack, the location of ignition has very little influence on eventual fire size (Table 1).

Our results confirm the relationship between roads and fire ignitions reported by others (Yang et al. 2006; Brosofske et al. 2007; Maingi and Henry 2007; Morrison 2007; Arienti et al. 2009; Narayanaraj and Wimberly 2012; Ricotta et al. 2018). Regardless of climate, vegetation, or differences in regional cultures, ignition density is higher near roads. Building new roads is likely to increase fire ignitions. Curiously, this is true for both human-caused and—to a lesser degree—lightning-ignited fires. In the case of human-caused fire, it is easy to explain the association as a result of recreational negligence (hot catalytic converters, discarded cigarette butts, unattended campfires, etc.) or arson (Brosofske et al. 2007; Fusco et al. 2016; Balch et al. 2017; Syphard et al. 2025).

The weak association between roads and lightning fires is harder to explain and could possibly be due to misattribution of human-caused fires, but our findings are not unprecedented. The association between roads and the invasion of flammable grasses is well established (D'Antonio and Vitousek 1992; Greenberg et al. 1997; Trombulak and Frissell 2000; Gucinski et al. 2001; Healy 2020). In a study of boreal forest in Alberta, Arienti et al. (2009) found a positive association between lightning fire frequency and road density, which they attributed to the increased availability of flammable fine-fuels near roads, after ruling out increased detectability (95% of fires were detected either from the air or from a lookout tower) and increased frequency of lightning strikes near roads. Similarly, Narayanaraj and Wimberley (2012) found a relationship between lightning-caused fire and proximity to gravel roads, which they suggested may be related to fuels near roads, but they did not rule out detection bias as a possible cause. Beyond the immediate road influence zone, the general decrease in ignition density with distance may be due to road effects, but it may also be explained as a decrease in detection probability with distance or even by the fact that more remote areas tend to be found at higher elevations where progressively cool, moist conditions may limit ignition. Regardless, the zone nearest roads clearly experiences elevated ignition density relative to the rest of the landscape.

While the association between roads and ignitions is well known, the association with area burned is less clear. Whether a place burns is a function not just of the frequency of ignitions but also the spread of fire. Several authors report higher ignition rates but smaller fire sizes where human influence is greatest, a phenomenon that Camp and Krawchuk (2017) call "the WUI fire paradox"—referring to the area known as the "Wildland Urban Interface." Dickson et al. (2006) examined wildfire patterns on the Mogollon Rim in Arizona and found that probability of occurrence was greatest in areas of high topographic roughness and lower road density and speculated that slow firefighter response times and limited access may be to blame, though they are clear not to suggest that fire occurrence could be reduced by the construction of new roads. Both Parisien et al. (2012) and Syphard et al. (2008) found fire occurrence to peak at an intermediate distance from human activity, eventually attenuating with remoteness.

Downing et al. (2022) evaluated the common perception that fires start on remote public lands and move onto private lands where they threaten communities and contrasted that narrative with an alternative that ignitions are more widespread. Under the first scenario, community protection can be achieved by reducing fire occurrence on public land; under the second, community protection is best achieved by addressing fire risk within developed areas. They found that rather than originating on public lands, most fires that cross boundaries originate on private lands and are associated with population density and roads. For cross-boundary fires that originate on national forests, "road density was the most important variable and demonstrated a strong positive association with ignitions." They conclude that increasing resilience of fire-adapted communities is a more rational approach to risk reduction than trying to exclude fire "based on the mistaken assumption that more fire suppression expenditures will result in less fire activity."

In the most direct assessment of the effects of roadlessness on fire, Johnston et al. (2021) examined ignition rates and fire sizes in roaded and roadless areas across the national forests of the western US from 1984 to 2017. Though the area of the two zones was comparable, roadless areas (wilderness and Inventoried Roadless Areas) experienced one third of the ignitions experienced in the roaded portion of the national forest system. Despite the lower ignition rate, the number of fires larger than 121 ha was similar between zones, and the size of these fires was found to be roughly one third larger on average in roadless areas than in the roaded landscape. Further, they found 30% of roadless lands to have burned over the study period compared to 18% of roaded lands, a fact they attributed to the lack of road access in roadless areas and the flexibility of managers "to allow fires to burn when these fires are compatible with resource management objectives or when suppression resources are strained by numerous large fire events." These findings contrast with those of Healy (2020), who found that "forests in roadless areas burned at similar frequencies as the rest of the [National Forest System]." Our results add to these findings by showing that it is not simply the land classification that matters; the differences are attributable to distance from roads. Some of the fires that Johnston et al. and Healy attributed to roadless areas no doubt started near roads adjacent to the roadless areas. Our analysis shows that, while the average size of fires that start near roads is smaller than those that start farther away, the average size and ignition density of fires that "escape" initial attack are similar across land classes. While roads may help keep some fires small, they also make them more numerous, and some of those fires will grow to become large fires. Constructing roads into roadless areas would simply increase the number of fires that need to be suppressed without having a meaningful impact on the likelihood of a large fire igniting.

As Johnston et al. (2021) and others have suggested, there are a number of reasons why the average fire size in roadless areas might be larger. One obvious reason is that roads, while increasing ignition, also likely increase detectability and provide access to suppression equipment and personnel. As discussed, roads also break up fuels and provide the infrastructure for both direct and indirect attack (O'Connor et al. 2017). But there is also considerable evidence that roadless areas are used by incident managers both as places where fuel reduction objectives can be achieved at minimal risk to HVRA (i.e., infrastructure) and where fires simply do not need to be fought when resources are stretched thin (Dunn et al. 2017; Johnston et al. 2021). In an analysis of five high-profile fires that burned in Utah in 2018, Aplet (2019) found roadless areas not to have hindered fire management but rather to have aided incident decision-making. Similarly, an analysis of fire suppression activities during the 2002 Hayman Fire in Colorado reported that a whole division of the fire line in the Lost Creek Wilderness was left unstaffed "due to its low priority" (McHugh and Gleason 2003). Roadless areas, because of their low density of values at risk, represent places where fires can be left to burn without endangering the welfare of firefighters or needlessly deploying precious suppression resources.

For these same reasons, roadless areas are also excellent candidates for the return of fire. Since the 1960s, when both the National Park Service and the US Forest Service began to reconsider their policy of fire exclusion, wilderness and other remote areas have been the targeted location for a policy, variously known as "Let Burn," "Prescribed Natural Fire," and "Wildland Fire Use," of allowing lightning fires to do their ecological work (Aplet 2006; van Wagtendonk 2007). Since 1995, the benefits of natural fire have been recognized in national policy (USDI & USDA 1995; U.S. Department of the Interior et al. 2001), and in 2009, the "Guidance for Implementation" of federal fire policy directed, "Wildland fire will be used to protect, maintain, and enhance resources and, as nearly as possible, be allowed to function in its natural ecological role" (Fire Executive Council 2009). Despite the successful reintroduction of lightning fire to several national parks and wilderness areas over the past half century (Parsons 2000; Miller and Aplet 2016), and recent increases in the amount of area burned across the USA, a "fire deficit" persists relative to historical levels of wildfire (Parks et al. 2025). Fulfilling the intent of national wildfire policy to allow fire to "as nearly as possible, be allowed to function in its natural ecological role," to reduce fuels and restore habitat, will take concerted effort across all levels of government and a redoubling of efforts to return fire to the land (Christiansen 2015; North et al. 2015; Miller and Aplet 2016; Thompson et al. 2016). Roadless areas provide a valuable asset for the achievement of that goal.

One strategy that has been repeatedly suggested over the past several decades to facilitate the return of fire is to zone the landscape according to different fire management objectives (Arno and Brown 1989; Aplet and Wilmer 2010; North et al. 2015; Thompson et al. 2016; USFS 2024). Common to all of these approaches is the notion that there are some parts of the landscape where we do not want fires to burn, other places that are far enough away from those "values at risk" that we can allow fires to burn on their own terms, and a tension zone in between, where we are not yet comfortable with fire, and we will need to intentionally manipulate both fire and fuels. In each case, wilderness and roadless areas provide the backbone of a strategy to facilitate fire's return to fire-dependent ecosystems. This notion was most recently endorsed by a group of leading fire scientists, who declared, "Strategic fire zones are essential to wildfire risk reduction in the Western United States" (North et al. 2024).

While strategic fire-management zones clarify multiple objectives across the fire-management landscape, in practice, decisions about objectives will need to be made at a finer scale (Thompson et al. 2016). Since 2016, various authors have proposed the idea of dividing the landscape into what they call "Potential Operational Delineations" or "PODs," which are "polygon[s] or container[s] whose boundaries are defined by features suitable for fire control (e.g., ridgetops and roads), and within which information on ecological conditions, fire risks, management opportunities, and strategic objectives can be summarized" (Thompson et al. 2022). In other words, PODs are units of the landscape, defined by roads and other "potential control locations" and generally on the order of a few thousand to a few tens of thousands of hectares, that can be used to assign objectives for application before, during, and after a fire (Dunn et al. 2020). Thompson et al. (2022) argue that each POD should be oriented to a specific "response category," consistent with the zones discussed above. Collaborating on action at the scale of PODs, combining the strategic benefits of both roads and roadless areas, provides a promising means to "eat the elephant" created by more than a century of fire exclusion and forest degradation (Caggiano 2019; Thompson et al. 2022).

In conclusion, our results suggest that building roads into roadless areas is likely to result in more fires. These fires will, on average, be smaller than fires farther from roads, but there will be more of them, and some of them will grow to become large fires. Nevertheless, both roads and roadless areas can contribute to strategic, landscape fire management. Where roads exist, they can be evaluated for their environmental effects and contribution to defining PODs. Where they are not needed, they can be retired to restore the roadless areas at the heart of many PODs. As our results show, roads can have both positive and negative effects on fire management. They can be a source of accidental (or arson) fire, but they can also create barriers to the spread of desirable fire under less-than-extreme conditions. Clearly, roads provide tactical advantage to firefighters, but given the established effect on ignition density, building more roads into existing roadless areas is not likely to aid the current challenge. Instead, the greatest benefit of roads may be in helping to define "a broader, adaptive framework of strategic fire-management planning that is cross-boundary, collaborative, and designed to improve alignment between fire management and land management decisions," i.e., PODs (Thompson et al. 2022). While their environmental impacts are well understood and must be accounted for, ironically, the existing road network, and the roadless areas they define, may provide the only way out of our current wildfire crisis.

Abbreviations

HVRA	Highly valued resources and assets
POD	Potential Operational Delineation
USFS	United States Forest Service

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s42408-026-00450-2.

Supplementary Material 1.

Acknowledgements

We thank two anonymous reviewers for sharing highly relevant references that had escaped our detection and for their skillful editing, which greatly improved the manuscript.

Authors' contributions

GA, PH, and MD conceived of the study and designed the study methods. GA was a major contributor in writing the first draft of the manuscript. PH and MD were secondary contributors in writing the first draft of the manuscript, and GA, MD, and PH edited the first draft and subsequent drafts. PH analyzed the nationwide fire data. All authors read and approved the final manuscript.

Funding
Funding for this study was provided by The Wilderness Society, sourced from donors unknown to the authors.

Data availability
Designated Wilderness Areas [Dataset]. 2024. U.S. Department of Agriculture Forest Service. (https://data.fs.usda.gov/geodata/edw/datasets.php).
InFORM Fire Occurrence Data Records [Dataset]. 2024. National Interagency Fire Center. (https://data-nifc.opendata.arcgis.com/datasets/inform-fire-occurrence-data-records/explore).
Inventoried Roadless Areas [Dataset]. 2024. U.S. Department of Agriculture Forest Service. (https://data.fs.usda.gov/geodata/edw/datasets.php).
National Forest System Lands [Dataset] 2024. U.S. Department of Agriculture Forest Service. (https://data.fs.usda.gov/geodata/edw/datasets.php).
National Forest System Lands [Dataset] 2024. U.S. Department of Agriculture Forest Service. (https://data.fs.usda.gov/geodata/edw/datasets.php).
TIGER/Line shapefiles [Dataset]. 2024. *TIGER/Line nationwide roads*. U.S. Census Bureau, U.S. Department of Commerce. (https://www.census.gov/geographies/mapping-files/time-series/geo/tiger-line-file.html).

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Author details
[1]The Wilderness Society, 1660 Wynkoop Street, Suite 1150, Denver, CO 80202, USA. [2]The Wilderness Society, 89 Sunset Ave., Great Diamond Island, Portland, ME 04109, USA.

Received: 22 May 2025 Accepted: 16 January 2026
Published online: 29 January 2026

References
Aplet, G. 2006. Evolution of wilderness fire policy. *International Journal of Wilderness* 12 (1): 9–13.
Aplet, G. 2019. Letter to the honorable Gary R. Herbert, Governor, State of Utah. https://www.dropbox.com/scl/fi/ari7nrgfopmuym0hs8tn4/Aplet-letter-to-Governor-Herbert.pdf?rlkey=u8p6ij9atjwf16uzto5owha0k&dl=0. Accessed 5 May 2025.
Aplet, G.H., and B. Wilmer. 2010. The potential for restoring fire-adapted ecosystems: Exploring opportunities to expand the use of fire as a natural change agent. *Fire Management Today* 70 (1): 36–39.
Arienti, M.C., S.G. Cumming, M.A. Krawchuk, and S. Boutin. 2009. Road network density correlated with increased lightning fire incidence in the Canadian western boreal forest. *International Journal of Wildland Fire* 18: 970–982.
Arno, S.F., and J.K. Brown. 1989. Managing fire in our forests—time for a new initiative. *Journal of Forestry* 87 (12): 44–46.
Balch, J.K., B.A. Bradley, J.T. Abatzoglou, and A.L. Mahood. 2017. Human-started wildfires expand the fire niche across the United States. *Proceedings of the National Academy of Sciences* 114 (11): 2946–2951.
Brosofske, K.D., D.T. Cleland, and S.C. Saunders. 2007. Factors influencing modern wildfire occurrence in the Mark Twain National Forest, Missouri. *Southern Journal of Applied Forestry* 31 (2): 73–83.
Caggiano, M.D. 2019. Collaboratively engaging stakeholders to develop potential operational delineations. CFRI-1908. https://cfri.colostate.edu/wp-content/uploads/sites/22/2019/08/PODs-Collaborative-Engagement-Final-Report.pdf. Accessed 5 May 2025.
Calkin, D.E., K.M. Gebert, J.G. Jones, and R.P. Neilson. 2005. Forest Service large fire area burned and suppression expenditure trends, 1970-2002. *Journal of Forestry* 103: 179–183.
Camp, P.E., and M.A. Krawchuk. 2017. Spatially varying constraints of human-caused fire occurrence in British Columbia, Canada. *International Journal of Wildland Fire* 26: 219–229.
Cardille, J.A., S.J. Ventura, and M.G. Turner. 2001. Environmental and social factors influencing wildfires in the Upper Midwest, United States. *Ecological Applications* 11 (1): 211–127.
Christiansen, E.C. 2015. Fuels treatments in the 21st century—do they matter? In *Proceedings of the large wildland fires conference*; May 19–23, 2014; Missoula, MT. Proc. RMRS-P-73, ed. R.E. Keane, M. Jolly, R. Parsons, and K. Riley. 267–268. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.
D'Antonio, C.M., and P.M. Vitousek. 1992. Biological invasions by exotic grasses, the grass fire cycle, and global change. *Annual Review of Ecology and Systematics* 23: 63–87.
DellaSala, D.A., and E. Frost. 2001. An ecologically based strategy for fire and fuels management in national forest roadless areas. *Fire Management Today* 61 (2): 12–23.
Dickson, B.G., J.W. Prather, Y. Xu, H.M. Hampton, E.N. Aumack, and T.D. Sisk. 2006. Mapping the probability of large fire occurrence in northern Arizona, USA. *Landscape Ecology* 21: 747–761.
Downing, W. M., C. J. Dunn, M. P. Thompson, M. D. Caggiano, and K. C. Short. 2022. Human ignitions on private lands drive USFS cross-boundary wildfire transmission and community impacts in the western US. *Scientific Reports* 12:2624.
Dunn, C.J., M.P. Thompson, and D.E. Calkin. 2017. A framework for developing safe and effective large-fire response in a new fire management paradigm. *Forest Ecology and Management* 404: 184–196.
Dunn, C. J., C. D. O'Connor, J. Abrams, M. P. Thompson, D. E. Calkin, J. D. Johnston, R. Stratton, and J. Gilbertson-Day. 2020. Wildfire risk science facilitates adaptation of fire-prone social-ecological systems to the new fire reality. *Environmental Research Letters* 15 : 025001.
Fire Executive Council. 2009. *Guidance for implementation of federal wildland fire management policy*. USDA and USDI, Washinton, DC. https://www.doi.gov/sites/default/files/uploads/2009-wfm-guidance-for-implementation.pdf. Accessed 5 May 2025.
Fusco, E.J., J.T. Abatzoglou, J.K. Balch, J.T. Finn, and B.A. Bradley. 2016. Quantifying the human influence on fire ignition across the western USA. *Ecological Applications* 26 (8): 2390–2401.
Grant, S.B., N.V. Rekhi, N.R. Pise, R.L. Reeves, M. Matsumoto, A. Wistrom, L. Moussa, S. Bay, and M.A. Kayhanian. 2003. *Review of the contaminants and toxicity associated with particles in stormwater runoff*. CTSW-RT-03–059.73.15. Caltrans, California Department of Transportation, Sacramento, CA.
Greenberg, C.H., S.H. Crownover, and D.R. Gordon. 1997. Roadside soils: A corridor for invasion of xeric scrub by nonindigenous plants. *Natural Areas Journal* 17 (2): 99–109.
Gucinski, H., M.J. Furniss, R.R. Ziemer, and M.H. Brookes. 2001. *Forest roads: a synthesis of scientific information*. Gen. Tech. Rep. PNWGTR-509. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 103 p.
Hawbaker, T.J., V.C. Radeloff, S.I. Stewart, R.B. Hammer, N.S. Keuler, and M.K. Clayton. 2013. Human and biophysical influences of fire occurrence in the United States. *Ecological Applications* 23 (3): 565–582.
Healy, S.P. 2020. Long-term forest health implications of roadlessness. *Environmental Research Letters* 15: 104023.
InFORM Fire Occurrence Data Records . 2024. National Interagency Fire Center. https://data-nifc.opendata.arcgis.com/datasets/inform-fire-occurrence-data-records/explore. Accessed 5 May 2025.
Inventoried Roadless Areas. . 2024. U.S. Department of Agriculture Forest Service. https://data.fs.usda.gov/geodata/edw/datasets.php. Accessed 5 May 2025.
Johnson, M.L., G. Pasternack, J. Florsheim, I. Werner, T.B. Smith, L. Bowen, M. Turner, J. Viers, J. Steinmetz, J. Constantine, E. Huber, O. Jorda, and J. Feliciano. 2002. *North Coast River Loading Study: road crossing on small streams*. Vol. I, Status of salmonids in the watershed. CTSW-RT-02–040. Sacramento, CA, Caltrans, California Department of Transportation.
Johnston, J. D., J. B. Kilbride, G. W. Meigs, C. J. Dunn, and R. E. Kennedy. 2021. Does conserving roadless wildland increase wildfire activity in western U.S. national forests? *Environmental Research Letters* 16 : 084040.

Jones, J.A., F.J. Swanson, B.C. Wemple, and K.U. Snyder. 2000. Effects of roads on hydrology, geomorphology, and disturbance patches in stream networks. *Conservation Biology* 14: 76–85.
Laschi, A., C. Foderi, F. Fabiano, F. Neri, M. Cambi, B. Mariotti, and E. Marchi. 2019. Forest road planning, construction and maintenance to improve forest fire fighting: A review. *Croatian Journal of Forest Engineering* 40:207–219.
Maffly, B. 2019. *Gov. Herbert seeks relief from roadless protections on Utah's forests; environmentalists fear unleashed logging*. Salt Lake Tribune, March 1, 2019. https://www.sltrib.com/news/environment/2019/03/01/herberts-petition-seeks/. Accessed 5 May 2025.
Maingi, J.K., and M.C. Henry. 2007. Factors influencing wildfire occurrence and distribution in eastern Kentucky, USA. *International Journal of Wildland Fire* 16: 23–33.
McHugh, C.W., and P. Gleason. 2003. Part 5: fire suppression activities. In *Hayman Fire case study*. Gen. Tech. Rep. RMRSGTR-114, tech. ed. R.T. Graham, 131–144. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.
Miller, C., and G. H. Aplet. 2016. Progress in wilderness fire science: Embracing complexity. *Journal of Forestry* 114 (3): 373–383.
Morrison, P. H. 2007. *Roads and wildfires*. Winthrop, WA: Pacific Biodiversity Institute.
Narayanaraj, G., and M.C. Wimberly. 2012. Influences of forest roads on the spatial patterns of human- and lightning-caused wildfire ignitions. *Applied Geography* 32: 878–888.
Narayanaraj, G., and M. C. Wimberly. 2013. Influences of forest roads and their edge effect on the spatial pattern of burn severity. *International Journal of Applied Earth Observation and Geoinformation* 23:62–70.
National Forest System Lands . 2024. U.S. Department of Agriculture Forest Service. https://data.fs.usda.gov/geodata/edw/datasets.php. Accessed 21 May 2025.
National Forest System Roads . 2024. U.S. Department of Agriculture Forest Service. https://data.fs.usda.gov/geodata/edw/datasets.php. Accessed 5 May 2025.
National Wilderness Areas. 2024. U.S. Department of Agriculture Forest Service. https://data.fs.usda.gov/geodata/edw/datasets.php. Accessed 21 May 2025.
Nellemann, C., I. Vistnes, P. Jordhoy, and O. Strand. 2001. Winter distribution of wild reindeer in relation to power lines, roads and resorts. *Biological Conservation* 101:351–360.
North, M.P., S.L. Stephens, B.M. Collins, J.K. Agee, G. Aplet, J.F. Franklin, and P.Z. Fulé. 2015. Reform forest fire management. *Science* 349: 1280–1281.
North, M.P., S.M. Bisbing, D.L. Hankins, P.F. Hessburg, M.D. Hurteau, L.N. Kobziar, M.D. Meyer, A.E. Rhea, S.L. Stephens, and C.S. Stevens-Rumann, C.S. 2024. Strategic fire zones are essential to wildfire risk reduction in the Western United States. *Fire Ecology* 20:50.
NWCG (National Wildfire Coordinating Group). 1996. *Wildland fire suppression tactics reference guide*. Boise, ID: National Interagency Fire Center.
O'Connor, C.D., D.E. Calkin, and M.P. Thompson. 2017. An empirical machine learning method for predicting potential fire control locations for pre-fire planning and operational fire management. *International Journal of Wildland Fire* 26: 587–597.
Parisien, M.A., S. Snetsinger, J.A. Greenberg, C.R. Nelson, T. Schoennagel, S. Dobrowski, and M.A. Moritz. 2012. Spatial variability in wildfire probability across the western United States. *International Journal of Wildland Fire* 21: 313–327.
Parks, S.A. 2025. Fire in wilderness ecosystems. In *Wilderness management: stewardship and protection of resources and values*, ed. C.P. Dawson and J.C. Hendee, 209–234. Long Grove, IL: Waveland Press.
Parks, S. A., C. H. Guiterman, E. Q. Margolis, M. Lonergan, E. Whitman, J. T. Abatzoglou, D. A. Falk, J. D. Johnston, L. D. Daniels, C. W. Lafon, R. A. Loehman, K. F. Kipfmueller, C. E. Naficy, M.-A. Parisien, J. Portier, M. C. Stambaugh, A. P. Williams, A. P. Wion, and L. L. Yocom. 2025. A fire deficit persists across diverse North American forests despite recent increases in area burned. *Nature Communications* 16 : 1493.
Parsons, D.J. 2000. The challenge of restoring natural fire to wilderness. In *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, comps. D.N. Cole, S.F. McCool, W.T. Borrie, and J. O'Loughlin, 276–282. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.
Reed, R.A., J. Johnson Barnard, and W.L. Baker. 1996. Contribution of roads to forest fragmentation in the Rocky Mountains. *Conservation Biology* 10: 1098–1106.
Ricotta, C., S. Bajocco, D. Guglietta, and M. Conedera. 2018. Assessing the influence of roads on fire ignition: Does land cover matter? *Fire* 1 : 24.
Scott, J.H., M.P. Thompson, and D.E. Calkin. 2013. *A wildfire risk assessment framework for land and resource management. Gen. Tech. Rep. RMRS-GTR-315*. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.
Smith, L.L., and C.K. Dodd. 2003. Wildlife mortality on US highway 441 across Paynes Prairie, Alachua County, Florida. *Florida Scientist* 66: 128–140.
Stergiadou, A. 2014. Prevention and suppression of forest-fires by using the road network and water tanks. *Fresenius Environmental Bulletin* 23 (11): 2755–2761.
Syphard, A.D., V.C. Radeloff, J.E. Keeley, T.J. Hawbaker, M.K. Clayton, S.I. Stewart, and R.B. Hammer. 2007. Human influence on California fire regimes. *Ecological Applications* 17 (5): 1388–1402.
Syphard, A.D., V.C. Radeloff, N.S. Keuler, R.S. Taylor, T. Hawbaker, S.I. Stewart, and M.K. Clayton. 2008. Predicting spatial patterns of fire on a southern California landscape. *International Journal of Wildland Fire* 17: 602–613.
Syphard, A. D., J. E. Keeley, E. Conlisk, and M. Gough. 2025. Regional patterns in U.S. wildfire activity: The critical role of ignition sources. *Environmental Research Letters* 20 : 054046.
Thompson, M.P., P. Bowden, A. Brough, J.H. Scott, J. Gilbertson-Day, A. Taylor, J. Anderson, and J.R. Haas. 2016. Application of wildfire risk assessment results to wildfire response planning in the southern Sierra Nevada, California, USA. *Forests* 7: 64.
Thompson, M. P., B. M. Gannon, and M. D. Caggiano. 2021. Forest roads and operational wildfire response planning. *Forests* 12 : 110.
Thompson, M.P., C.D. O'Connor, B.M. Gannon, M.D. Caggiano, C.J. Dunn, C.A. Schultz, D.E. Calkin, B. Pietruszka, S.M. Greiner, R. Stratton, and J.T. Morisette. 2022. Potential operational delineations: New horizons for proactive, risk-informed strategic land and fire management. *Fire Ecology* 18: 17.
TIGER/Line shapefiles . 2024. *TIGER/Line nationwide roads*. U.S. Census Bureau, U.S. Department of Commerce. https://www.census.gov/geographies/mapping-files/time-series/geo/tiger-line-file.html. Accessed 5 May 2025.
Trombulak, S.C., and C.A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology* 14: 18–30.
United States Department of the Interior, United States Department of Agriculture, Department of Energy, Department of Defense, Department of Commerce, U.S. Environmental Protection Agency, Federal Emergency Management Agency, National Association of State Foresters. 2001. *Review and update of the 1995 federal wildland fire management policy*. Boise, ID: National Interagency Fire Center.
USDI & USDA. 1995. *Federal wildland fire policy and program review: final report*. Washington, DC: United States Department of the Interior and United States Department of Agriculture.
USFS. 2024. *Northwest Forest Plan amendment draft environmental impact statement, volume 2: appendices*. USDA Forest Service, Pacific Southwest and Pacific Northwest Regions.
van Wagtendonk, J.W. 2007. The history and evolution of wildland fire use. *Fire Ecology* 3: 3–17.
Yang, J., H. S. He, H. S. He, S. R. Shifley, and E. J. Gustafson. 2006. Spatial patterns of modern period human-caused fire occurrence in the Missouri Ozark Highlands. *Forest Science* 53 (1): 1–15.
Yocom, L.L., J. Jenness, P.Z. Fule, and A.E. Thode. 2019. Previous fires and roads limit wildfire growth in Arizona and New Mexico, U.S.A. *Forest Ecology and Management* 449: 117440.
Zumbrunnen, T., P. Menendez, H. Bugmann, M. Conedera, U. Gimmi, and M. Burgi. 2012. Human impacts on fire occurrence: A case study of hundred years of forest fires in a dry alpine valley in Switzerland. *Regional Environmental Change* 12:935–949.

Publisher's Note

Gregory H. Aplet GA is Senior Forest Ecologist at The Wilderness Society and lives in Arvada, CO.

Phil Hartger PH is Senior GIS Specialist at The Wilderness Society and lives in Denver, CO.

Matthew S. Dietz MD is Director of Science Applications at The Wilderness Society and lives in Portland, ME.