Human and climatic influences on wildfires ignited by recreational activities in national forests in Washington, Oregon, and California*

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Human and climatic influences on wildfires ignited by recreational activities in national forests in Washington, Oregon, and California*

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Abstract

In Washington, Oregon, and California, ignitions from recreational activities accounted for 12% of human-caused wildfires, and 8% of the area burned, from 1992–2020. Wildfires ignited by recreational activities not only increase fire suppression expenditures but have the potential to limit recreational activities traditionally associated with use of fire, such as camping. From 1992–2020, 50% of recreation-caused ignitions in these three states occurred on lands managed by the U.S. Forest Service. The mean annual number of recreation-caused ignitions on national forests in the three states during this period was relatively stable, about 500, whereas recreation-caused ignitions within other jurisdictions decreased by 40%. Improved understanding of the impact of human and climatic factors on recreation-caused ignitions could provide valuable insights for shaping policy and management decisions. We found that mean annual densities of recreation-caused ignitions on national forests were 7 times greater within 1 km of designated campgrounds than >1 km from campgrounds, although 80% of recreation-caused ignitions occured >1 km from designated campgrounds. Ignition density in campgrounds increased non-linearly with overnight visitor density; a doubling of visitor density was associated with a ~40% increase in ignitions. Large (⩾4 ha) recreation-caused wildfires, especially those ignited in designated campgrounds, tended to occur concurrent with drought and 1–2 years after anomalously wet conditions. These results suggest that accounting for drought in implementation of fire restrictions, and targeting wildfire-prevention awareness to recreational users outside designated campgrounds, might reduce the likelihood of recreation-caused ignitions.

1. Introduction

Fire is inextricably linked to the outdoor recreational experience in the United States. Fires are typically associated with camping given relatively cool overnight temperatures, fires' use in cooking, and the atmosphere that fires create for storytelling, rituals, and other social gatherings (Mechling 1980, Neaman *et al* (2010), Young 2017). Campsite selection by visitors is strongly related to the ability to build a campfire (Lillywhite *et al* 2013). Eighty-six percent of visitors surveyed at designated campgrounds ranked an appropriate place for a campfire, such as a ring or pit, as 'extremely important' to the camping experience (Peterson and Diss-Torrance 2012). Although the use of cookstoves for backcountry camping has become more common (Christensen and Cole 2000, Marion and Reid 2007), fire restrictions do not eliminate the construction of fire rings at dispersed camping locations. Instead, the persistent effects on soil and vegetation from compaction and wood gathering can make particular locations appear to be suitable for building a fire (Reid and Marion 2005).

Through inattention, negligence, or bad luck, campfires sometimes ignite wildfires that society wishes to suppress. From 1992 through 2020, ignitions associated with recreation and ceremony (recreation-caused

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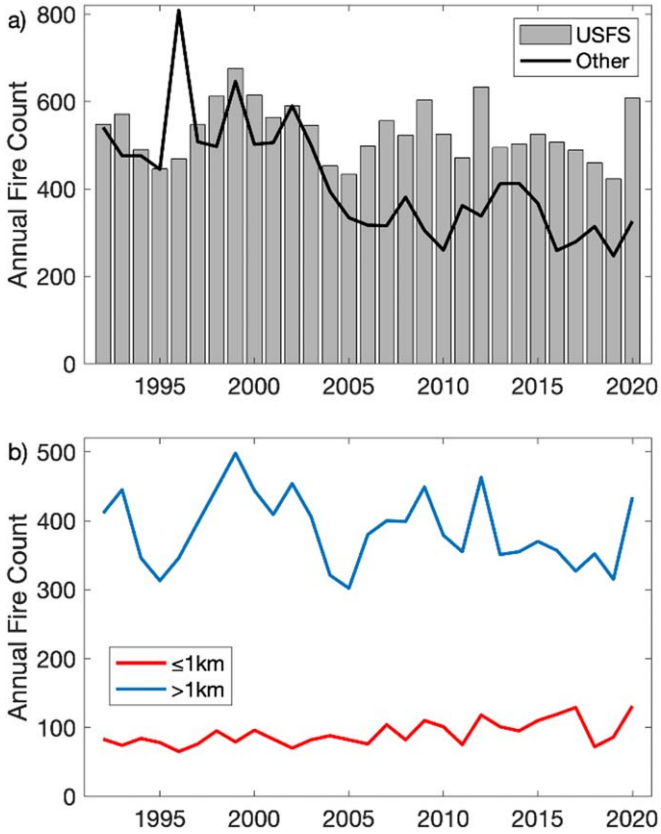

Figure 1. Annual number of recreation-caused wildfires on (a) U.S. Forest Service (USFS) lands and all other lands in Washington, Oregon, and California and (b) on USFS lands as a function of proximity to designated campgrounds.

ignitions) accounted for an estimated 12% of human-caused wildfires and 8% of the area burned by those wildfires in Washington, Oregon, and California (Short 2022). Collectively, these wildfires represented 29% of recreation-caused ignitions across the contiguous United States. Wildfires can threaten not only human lives and property but recreational opportunities. Across the western United States, an estimated 400,000 campground visitor days per year are affected by poor air quality as a result of wildfire smoke (Gellman *et al* 2022).

Some classes of human-caused wildfire ignitions, such as debris and open burning, primarily occur on private lands. By contrast, most recreation-caused ignitions occur on public lands. In the Pacific states from 1992–2020, half of recreation-caused ignitions occurred on lands managed by the U.S. Forest Service (USFS) (figure 1). The remaining half occurred on other federal lands (15%), lands under the jurisdiction of state, county, or local government (11%), private lands (15%), and areas under unspecified ownership or jurisdiction (9%). Strategies used by the USFS to limit the risk of recreation-caused ignitions include fire-permit requirements, forest closures, burn bans, and educational programs (Reid and Marion 2005). The mean annual number of recreation-caused wildfires within non-USFS lands in the Pacific states decreased by 40% from 1992–2020. Nevertheless, the mean annual number of recreation-caused ignitions on national forests remained around 500 over the same time period.

Since 1995, the number of recreational ignitions was higher in areas >1 km from designated campgrounds, which are often associated with dispersed camping, than in those within 1 km of designated campgrounds (figure 1). Although overnight visitors to designated campgrounds and visitors who spend the night elsewhere on national forests have different behavioral norms (e.g., expectations of minimum resource impacts), both user groups prioritize safe fire management as part of their camping experience (Basman *et al* 1996).

As the western United States becomes warmer and drier, the probability of large wildfires and the area burned are increasing (Abatzoglou and Williams 2016). Antecedent and current climate can affect fire likelihood and size. Large wildfires tend to be enabled by wet conditions in the prior growing season where vegetation is not continuous, and by dry conditions in the current growing season where vegetation is abundant and the climate generally limits widespread flammability (Littell *et al* 2009, Westerling *et al* 2003). However, fire warnings and restrictions primarily reflect weather conditions rather than antecedent climate and the volume of standing dry vegetation (de Groot *et al* 2015).

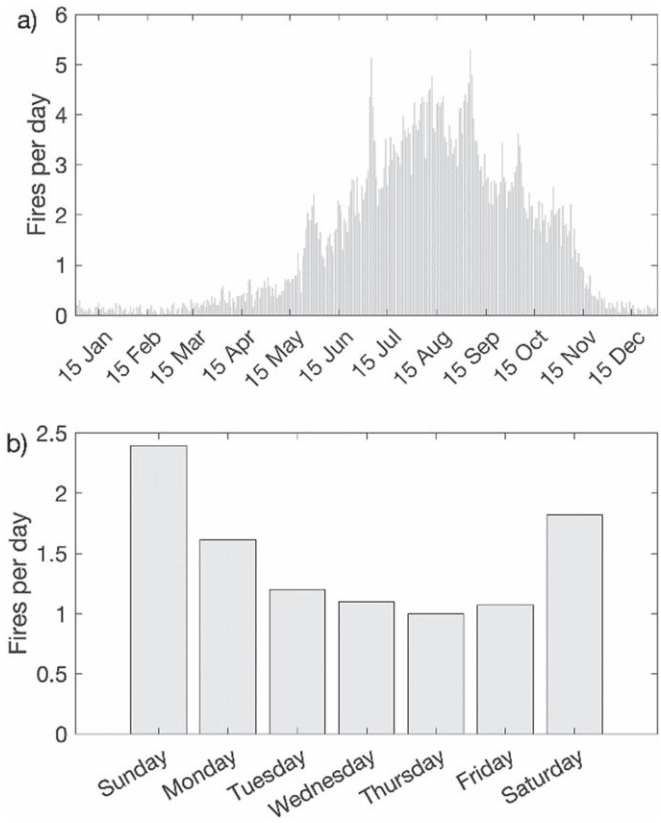

Figure 2. Mean annual number of wildfires ignited by recreation and ceremony on national forests in Washington, Oregon, and California by date and day of the week from 1992–2020.

Much camping occurs during summer, the driest season in the Pacific states, with peaks in ignitions around national holidays (e.g., Memorial Day, Independence Day, and Labor Day) and after the end of the federal fiscal year (September 30), when most campgrounds close. From 1992–2020, nearly twice as many fires occured on weekend days as on weekdays (figure 2).

We hypothesized that the density of wildfires ignited by recreation or ceremony on USFS lands, and the size of such wildfires, is influenced by human and climatic factors, including proximity to designated campgrounds, visitor density, antecedent and current drought conditions, and dominant vegetation type (trees, shrubs, grasses) surrounding the ignition point. We accounted for potentially confounding biogeographic effects of ecoregion given that vegetation composition and climate vary among ecoregions. For example, in the cool, moist coastal forests of Washington, Oregon, and northern California, lightning is rare and the number of large wildfires historically was low (Trouet *et al* 2006). By contrast, the mean historical fire return interval in chaparral-dominated ecosystems, such as those in central and southern California, was about 30–90 years (Water *et al* 2011).

2. Method

2.1. Data sources

Our source of data on the locations, discovery dates, ignition causes, and sizes of wildfires was the Fire Program Analysis fire-occurrence database (Short 2022), which recognizes recreation and ceremony among 13 causes of wildfires (10 human-caused, lightning, other, and unknown). This data covers recreation-caused ignitions that were not properly extinguised and ultimately became wildfire, whereas determining the number and location of all potential recreation and ceremony fire sources that could potentially lead to an ignition is not feasible. We do not focus on the probability that an ignition may happen, but rather the relationship between the number and size of recreation-caused ignitions, vegetation type, number of visitors, national forest area, proximity to campgrounds, and antecedent drought conditions.

We clipped the boundaries of the U.S. Environmental Protection Agency 2022 (Omernik and Griffith 2014) to the jurisdictional boundaries of the 34 national forests in Washington, Oregon, and California (figure 3). These ecoregions are defined on the basis of land use, land surface form, potential natural vegetation, and soils,

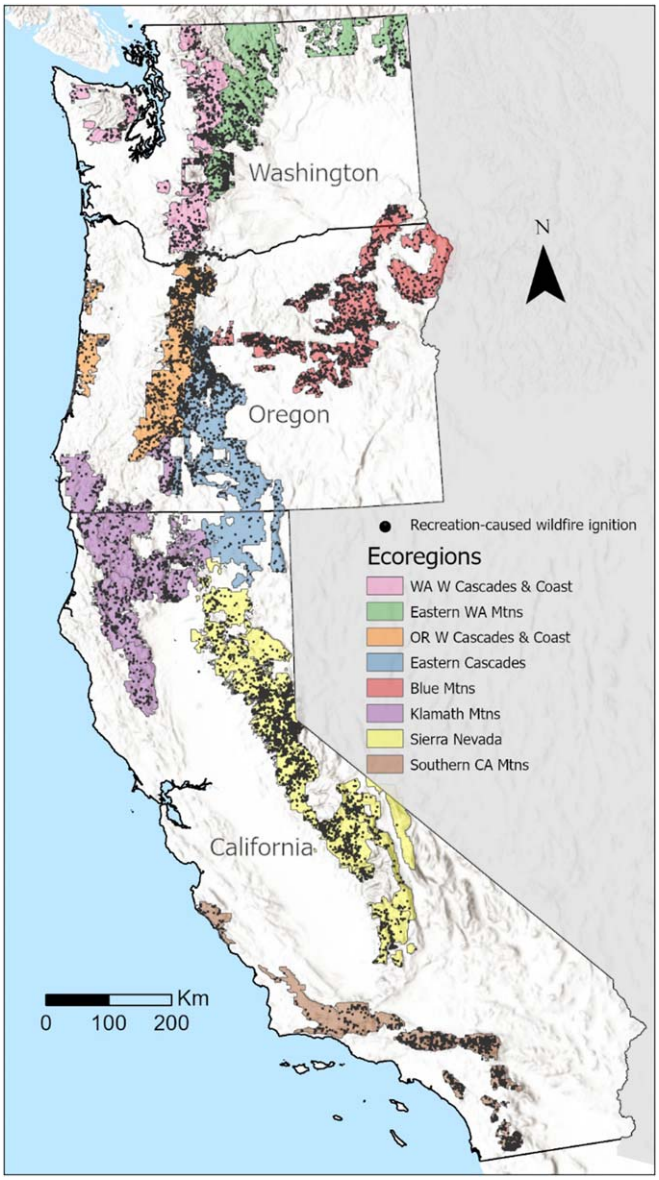

Figure 3. Recreation-caused wildfire ignitions on U.S. Forest Service lands and national forest boundaries within U.S. Environmental Protection Agency Level III ecoregions in Washington, Oregon, and California.

which in turn reflect physiography and climate (Omernik 1987). We identified the percentage of three vegetation types (trees, shrubs, and grasses) within a clipped 1 km buffer around each ignition point on the basis of a 2001 classification of imagery from the Moderate Resolution Imaging Spectroradiometer (MODIS) (MCD12Q1.061) (table 1).

We obtained data on the total number of overnight visitors to national forests from 2016–2020 from the USFS National Visitor Use Monitoring (NVUM) program (table 1). The NVUM uses a standardized sampling protocol to survey selected visitors to each unit of the National Forest System. National forests are included in NVUM on a rotating 5-year schedule, and the NVUM survey includes questions about visitor characteristics and activities (English *et al* 2020). The survey responses can be used to estimate the number of people participating in a given activity, including overnight camping within or beyond developed campgrounds, which we refer to as designated campgrounds.

Designated USFS campgrounds include developed campgrounds, group campgrounds, and camping areas (Bailey 2020). These campgrounds usually are near roads and have some amenities, such as parking pads, pit toilets, and fire rings or grills (Lillywhite *et al* 2013). Many campgrounds were built in the 1930s, by the Civilian Conservation Corps, or in the 1950s and 1960s, by Operation Outdoors, with the goal of constructing modern facilities and improving infrastructure (Sieker 1957). We classified ignitions as within or beyond 1 km (0.6 mi) of the single coordinates of a designated campground.

Table 1. Vegetation types within 1 km of ignitions caused by recreation and ceremony, mean annual number of overnight visitors, and national forest area and mean annual recreation-caused ignitions within and beyond 1 km of campgrounds for national forests within U.S. Environmental Protection Agency Level III ecoregions in Washington, Oregon, and California.

	% vegetation type within 1 km of ignition			Mean annual number of overnight visitors		National forest area (km^2 [mi^2])			Mean annual recreation-caused ignitions	
Ecoregion	Tree	Shrub	Grass	Designated campgrounds	Elsewhere	Total	Within 1 km of campgrounds	Beyond 1 km of campgrounds	Within 1 km of campgrounds	Beyond 1 km of campgrounds
Washington Western Cascades and Coast	99.3	0	0.7	88,918	94,232	17,078 (10,611)	361 (224)	16,716 (10,386)	6.4	33.2
Eastern Washington Mountains	88.8	2.5	8.7	76,048	69,346	22,704 (14,107)	597 (371)	22,107 (13,736)	8.3	32.0
Oregon Western Cascades and Coast	98.3	0.4	1.3	214,490	79,688	19,153 (11,901)	861 (535)	18,293 (11,366)	17.0	53.2
Eastern Cascades	72.3	1.8	25.8	102,335	12,960	27,151 (16,870)	481 (299)	26,670 (16,572)	7.2	64.1
Blue Mountains	61.8	4.6	33.6	32,419	19,812	27,206 (16,905)	456 (283)	26,750 (16,621)	3.9	61.7
Klamath Mountains	96.5	1.8	1.6	119,434	36,412	34,888 (21,678)	902 (560)	33,986 (21,118)	10.3	34.0
Sierra Nevada	58.0	27.8	14.2	571,946	207,361	44,482 (27,639)	2,271 (1,411)	42,210 (26,228)	23.3	86.0
Southern California Mountains	5.6	50.2	44.2	218,439	63,650	16,367 (10,169)	679 (422)	15,688 (9,748)	15.5	42.1

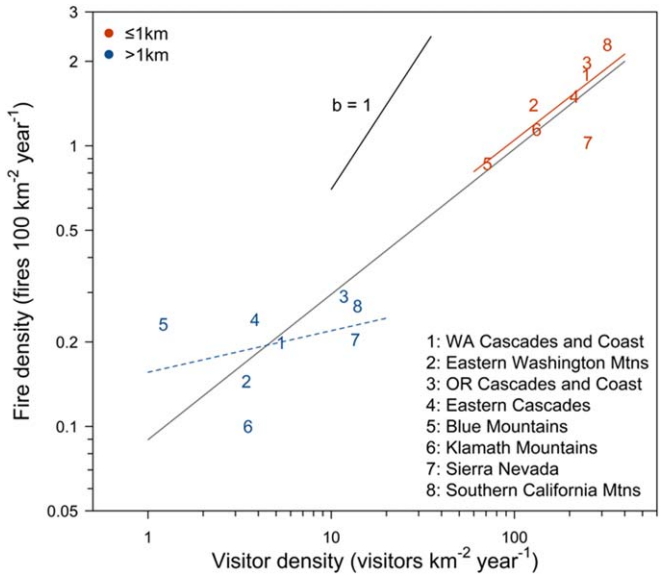

Figure 4. Mean annual density of wildfires ignited by recreation or ceremony ⩽1 km or >1 km from designated U.S. Forest Service campgrounds as a function of overnight visitor density. Lines show linear models fitted to log-transformed values. Solid fitted lines indicate where the power law exponent b is significantly different from zero. A power law with $b = 1$ is shown for reference.

We used the Palmer Drought Severity Index (PDSI) to quantify drought given widespread use of the index in drought monitoring and its established relation to the number of large wildfires and area burned (Westerling *et al* 2003, Trouet *et al* 2006). The standardized PDSI is based on modeled water supply and demand and represents the magnitude of departure from long-term average soil moisture (Dai *et al* 2004). We derived PDSI values for each ecoregion from gridMET (Abatzoglou 2013), which has a 4-km horizontal resolution.

2.2. Statistical analyses

We converted the annual number of recreation-caused ignitions to annual density (ignitions per km^2) ⩽1 km and >1 km from designated campgrounds. We then summed the density of ignitions that led to small (<4 hectares [10 acres]) and large (⩾4 hectares [10 acres]) wildfires in each ecoregion. We chose 4 ha because it represented the 97th percentile of the size of recreation-caused fires across the Pacific states. We estimated the area of designated campgrounds within each ecoregion as number of campgrounds $\times \pi \times 1$ km^2 and the remaining area as ecoregion area (clipped to USFS lands only) minus the campground area. We converted the annual number of visitors to visitor densities within and beyond campgrounds.

We used analysis of variance (ANOVA) to test whether annual recreation-caused ignition densities differed significantly within and beyond 1 km of designated campgrounds, between small and large fires, and among ecoregions. We used ordinary least squares regression to test whether the relation between mean log-transformed annual ignition density and visitor density varied among ecoregions, effectively assuming a power-law relationship, $y = ax^b$, between mean annual ignition density (y) and visitor density (x). We fitted linear models to all ignitions and to those within and beyond 1 km of designated campgrounds.

We related each ignition location to monthly PDSI in the preceding 1–25-months and to the percentage of trees, shrubs, and grasses within 1 km of the ignition. We used a Student's t-test to evaluate whether the percentage of the three vegetation types varied between ignitions that led to small and large fires and to large fires within and beyond 1 km of designated campgrounds.

3. Results

Mean annual densities of recreation-caused ignitions on national forests were 7 times greater within than beyond 1 km of designated campgrounds (figure 4). Densities of recreation-caused ignitions that remained small fires were 620% higher within than beyond 1 km of campgrounds ($p < 0.001$), and densities of ignitions that became large fires were 130% higher within 1 km of campgrounds ($p < 0.05$). The density of recreation-caused ignitions that resulted in both small and large wildfires differed significantly among ecoregions ($p < 0.001$ and $p < 0.05$, respectively). The mean annual density of all recreation-caused ignitions, and of those within 1 km of campgrounds that resulted in small fires, increased as a power law function of the annual density of overnight visitors. Values of the power law exponent, b, were 0.52 (95% confidence interval 0.42–0.62) and 0.51

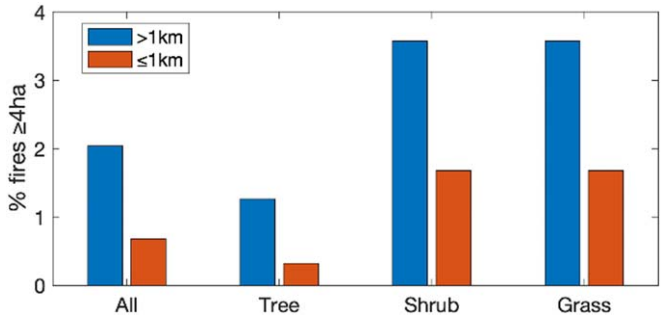

Figure 5. Percentage of recreation-caused ignitions that resulted in a large fire (⩾ 4 hectares [10 acres]) >1 or ⩽1 km from a designated U.S. Forest Service campground and dominant vegetation type within 1 km of the ignition.

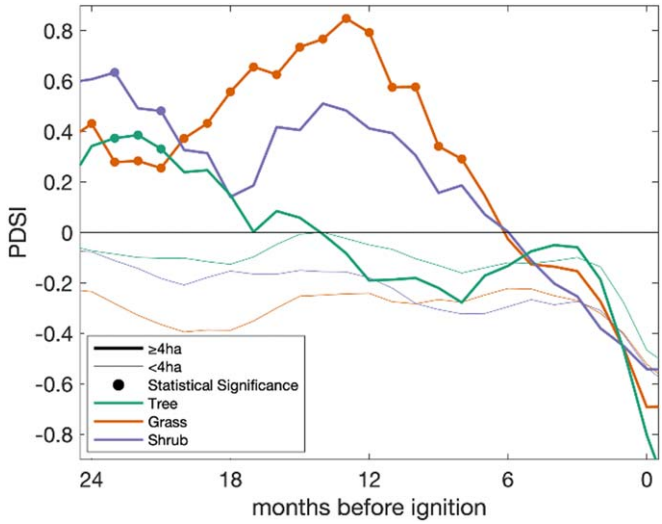

Figure 6. Composite monthly PDSI on the date of discovery, and up to 25 months preceding and one month following the discovery date, of large (⩾4 hectares [10 acres]) wildfires (bold) and small (<4 hectares) wildfires ignited by recreation or ceremony where vegetation within 1 km of the ignition location was dominated by trees (green), shrubs (purple), or grasses (orange). Dots indicate statistically significant ($p < 0.05$) differences between large and small fires for that vegetation type.

(0.07–0.94), respectively, for all ignitions and those within 1 km of campgrounds. Our results indicated that the density of ignitions increased by 43% (33%–54%) given a doubling of visitor density.

Among recreation-caused ignitions that resulted in large fires, the percentages of those that were ⩽1 km and >1 km from campgrounds were similar among vegetation types (figure 5). Ignitions >1 km from campgrounds were more than twice as likely as those ⩽1 km from campgrounds to result in large fires. Among ignitions >1 km from campgrounds, those surrounded by shrubs and grasses resulted in three times as many large fires than those surrounded by trees. Shrubs and grasses surrounded nearly six times more ignitions ⩽1 km from campgrounds that became large fires than did trees.

PDSI coincident with recreation-caused large fires was negative (dry conditions), and significantly lower in ignition areas dominated by trees than in areas dominated by grasses or shrubs (figure 6). Ignitions in grass-dominated areas that led to large fires were significantly associated with wet conditions ⩾12 months prior to the fire (generally the previous growing season), whereas large fires that ignited in areas dominated by trees or shrubs were significantly associated with wet conditions 24 months before the fire.

With respect to large fires, both concurrent (negative) and antecedent (positive) PDSI were more strongly associated with ignitions ⩽1 km from designated campgrounds than with those > 1 km from campgrounds (figure 7). The association with antecedent PDSI was especially pronounced in areas dominated by trees.

4. Discussion

Mean annual densities of recreation-caused ignitions were much higher near designated campgrounds (within 1 km) than in areas further away, which coincide with dispersed overnight camping. Designated campgrounds

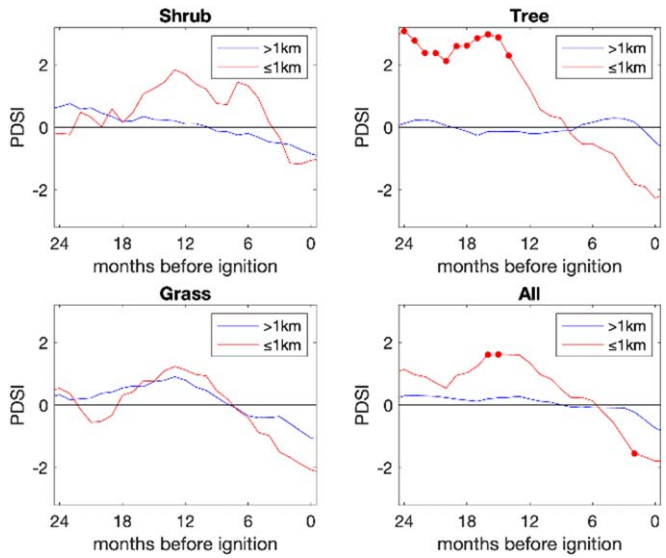

Figure 7. Composite monthly PDSI for large (⩾4 hectares [10 acres]) wildfires ignited by recreation or ceremony across U.S. Forest Service lands >1 km or ⩽1 km from a designated campground. Data are centered on the ignition month and preceeding 24 months. Dots indicate statistically significant ($p < 0.05$) differences between fires ignited within or beyond 1 km of designated campgrounds.

routinely are used overnight. The effects of such concentrated use in campgrounds, such as depletion of dead woody vegetation, trampled vegetation, and soil compaction (Hall and Farrell 2001), have the potential to confer resilience to fire, but also may mislead visitors about fire safety when attributes of weather and climate (e.g., wind, drought, atmospheric moisture) are conducive to wildfire (Brown *et al* 2004).

The accuracy of visitors' expectations about fire safety also can decline as a result of rapid transitions between drought and flooding (Swain *et al* 2018). This volatility poses challenges for communication of fire risk to experienced and new visitors, especially if users respond to extreme weather or smoke, fire restrictions, and national forest closures by visiting a different place or during a different season or year (Jenkins *et al* 2023, Perry *et al* 2021). We therefore suggest that communicators consider variability in hydroclimate and visitors' expectations, in addition to fire weather (de Groot *et al* 2015), when advising visitors about fire risk and the necessary mitigation and safety practices.

Ignitions in the vicinity of designated campgrounds represented a smaller percentage, approximately 20%, of annual ignitions on national forests in the Pacific state from 1992–2020 (figure 1). We suspect that areas in which backcountry use is concentrated (Jenkins *et al* 2021a) also may be associated with a high density of ignitions. Additionally, although the timing of peak visitor density varies among locations, more ignitions occur on weekends and holidays (figure 2), highlighting the effect of societal and cultural factors on fire occurrence (Balch *et al* 2017). More users may be displaced from weekend and holiday use to other times, locations, or activities as recreational fire restrictions and forest closures become more common in response to drought conditions during periods of high use.

The mean annual density of recreation-caused wildfire ignitions varied among ecoregions, and variability in densities of ignitions and visitors was greater >1 km from campgrounds than ⩽1 km from campgrounds (figure 4). Fire pits and rings at campgrounds undoubtedly create more opportunities for ignitions. Fire pits and rings are intended to reduce the risk of wildfire, but the perception of fire safety they confer may increase the likelihood of ignition if that perception results in inattention or incomplete extinguishment (Halpern and Pearl 2005). Conversely, in areas further from designated campgrounds, the absense of fire-suppression tools or visitors may enable a greater proportion of ignitions to evade discovery and become large wildfires (Johnston *et al* 2021), especially in areas with high fine fuel loads from growth of shrubs and grasses over preceeding seasons (figure 5).

The Eastern Washington Mountains ecoregion had the highest ratio of density of ignitions ⩽1 km from campgrounds to visitor density, and a high percentage of ignitions in this ecoregion were in tree-dominated vegetation. In contrast, the ratio of ignitions >1 km from campgrounds to visitor density was highest in the Blue Mountains and Eastern Cascades, and a high percentage of fires in these ecoregions ignited in grass-dominated vegetation.

Densities of ignitions and visitors were highest in the two smallest ecoregions, the Washington and Oregon Cascades and Coast and the Southern California Mountains ecoregions. These ecoregions are the smallest and

are near urban population centers. The former ecoregions primarily are forested, whereas most of the latter is covered by chaparral with relatively short fire-return intervals (Water *et al* 2011).

The ratio of ignition density to visitor density was low in the Klamath Mountains and Sierra Nevada, both of which are relatively large. The Klamath Mountains are relatively wet, with a high percentage of tree cover, and lightning-caused fire is rare (Bidlack *et al* 2021). Density of visitors was highest in the Sierra Nevada, and a relatively high percentage of ignitions in this ecoregion occurred in shrubland in which the historical frequency of fire was linked to climatic variability (Taylor *et al* 2016).

The fact that ignition density was a non-linear function of visitor density may be related to high use of public lands and an increasing number of first-time visitors who may not be familiar with minimum impact principles and local ecology, including fire safety or fire-use restrictions (D'Antonio *et al* 2012, Jenkins *et al* 2021b). The non-linear relation between ignition density and visitor density also may imply that a shift from dispersed camping to use of designated campgrounds could reduce the total number of ignitions and the number that lead to large wildfires. Dispersed camping and wilderness permits are based on the number of overnight visitors. These visitors tend to be individuals or smaller groups. There are no formal limits on number of users across much of the National Forest System. By contrast, campground capacity is usually limited on the basis of parking capacity per campsite, generally one or two vehicles, which corresponds to a maximum of about 4 to 8 people. Therefore, the number of visitors who participate in dispersed camping likely is positively correlated with the number of trips, whereas the number of visitors at campgrounds is not. The greater number of visitors per ignition source near campgrounds, and campsite attributes such as a fire ring or absence of vegetation, may reduce the potential for wildfire ignition.

Large recreation-caused fires were more likely than small fires to occur during periods of drought (figure 6). This effect was more pronounced in areas dominated by trees, especially when soils were anomalously wet during the preceding 24 months. By contrast, wet conditions 12 months in advance of the ignition were associated with large fires where shrubs and grass dominated the near-ignition vegetation. Primary productivity in grass and shrub-dominated ecosystems in the western United States generally responds positively to antecedent precipitation. The link between vegetation growth and burned area in these systems is strong (Littell *et al* 2009). Although concurrent fire danger often informs issuance of fire restrictions on national forests, our results suggested that considering anomalously wet conditions in the previous 1–2 years also may be warranted.

Large fires that ignited within 1 km of designated campgrounds were more likely to be associated with antecedent wet conditions and concurrent drought than large fires that ignited >1 km from designated campgrounds (figure 7). This relation was significant everywhere, but particularly where trees dominated the vegetation surrounding an ignition. Fires >1 km from campgrounds were more likely to become large when drought was less extreme between antecedent and concurrent drought conditions.

Our results therefore suggest that the likelihood of recreation-caused wildfires could be reduced if longer-term drought metrics are used to inform fire restrictions and wildfire-prevention awareness is extended to visitors outside designated campgrounds.

5. Conclusion

Human factors, such as proximity to campgrounds and visitor density, climate conditions, and dominant vegetation type surrounding an ignition contribute to recreation-caused wildfire ignitions in different ways. Here we demonstrated that mean annual densities of recreation-caused ignitions were much higher near designated campgrounds than in areas further away. Recreation-caused ignitions were twice as likely to become large wildfires when >1 km from a campground than within 1 km of a campground, which may in part reflect challenges and delays in suppression. Large fires were more likely in areas surrounded by shrubs and grasses than by trees, and twice as likely if the ignition was within 1 km of a designated campground.

We suggest that visitor education about fire safety practices and the basis for restriction measures emphasize annual variability and volatity in the frequency and magnitude of drought, It is conceivable that visitors who are affected by national forest closures in a given year expect safer conditions during the following year, and do not consider vegetation accumulation or climate during the intervening period. This is particularly important given that many escaped recreation-caused ignitions began as unattended or smoldering fires, and that near designated campgrounds, these fires are more likely when fine fuels are dense.

Future research might consider the coincidence of recreation-caused fires with other human-caused fire types, such as fireworks and smoking, that may be associated with higher levels of visitor use during holidays and weekends. Further analyses would benefit from greater availability of fire restriction information, including a central, multiagency repository for the seasonal start and end dates of limits on fire use, closures due to fire risk, and as a record of the factors that affected local decisions about fire restrictions.

Much of the recreational fire use in other jurisdictions, such as national, state, and local parks, occurs in campgrounds. The use of fire elsewhere in these jurisdictions, such as in roadless wilderness areas, is increasingly limited to portable gas stoves. Subsequent research might therefore focus on areas with consistently dense overnight use in designated campgrounds and in the backcountry. Recreation-caused ignitions are also associated with holidays and periods of high use, and conditions during these times are changing with the climate. Future research should therefore assess the coupled likelihood for recreation-caused ignitions from both changing climatic factors and influence on vegetation, and the convergence with high levels of use during peak season when conditions are most conducive for wildland fire, the potential for which is changing with the climate.Other land management agencies might benefit from an analysis similar to that presented here. Such an analysis would entail consideration of proximity to campgrounds, visitor use levels, and antecedent and concurrent drought conditions. The results could inform allocation of resources for the communication of fire risk and safety practices, and ultimately guide visitors' behaviors associated with front country or dispersed use.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files). Data will be available from 30 September 2023.

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